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The neurodynamics of the stock market

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1. Introduction

Stock price variation is in sharp contrast with the stability of conservative investments such as treasury bonds, bank certificates, etc. and affects the investor decision as well as the economy performance. From time to time, noise in the financial market increases significantly and investors promote large fluctuation of stock prices in respect to the economy fundamental values. Exaggerated optimism promotes unjustified increases of bourse indices while pessimism drives decision-making during crises. Bubbles and crashes are hallmarks of the stock market and define economic cycles. Fig. 1A shows the evolution of the Dow Jones index during the period January, 2, 2007 to December, 30, 2008, and illustrates this oscillatory behavior of the financial market.

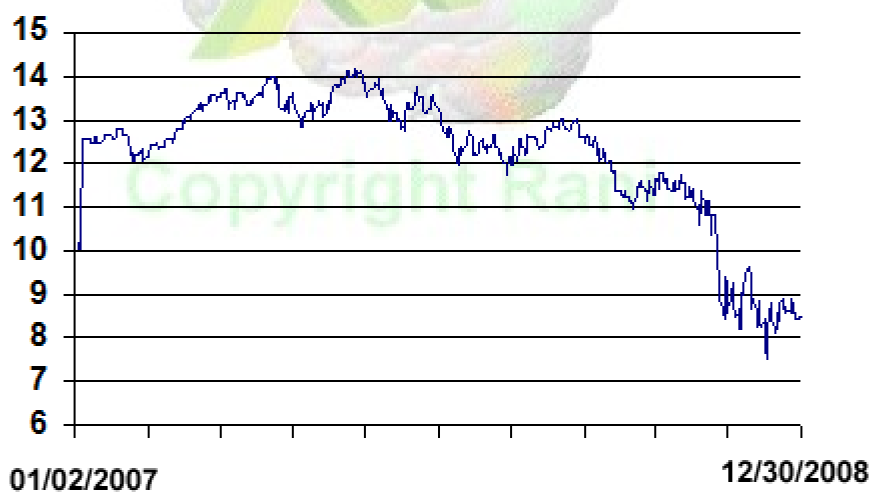

Figure 1 – The evolution of the Dow Jones Index
from January, 2, 2007 to December, 30, 2008

The uncertainty of the financial market turns the investors dependent on relative price evaluation anchored on previous stock prices and market indices. In this context, we proposed that the closing price $p^{c}_{s_i}(n)$ of the stock s_i of the company c_j in the n^{th} stock trade shall be anchored in the proposed selling $p^{s}_{s_i}(n)$ and buying $p^{b}_{s_i}(n)$ prices offers, which in turn are anchored on the history of $p^{c}_{s_i}(k)$, for $k < n$; the trust on the market and the trust on c_j. Rocha proposed a neuroeconomic to model this price anchoring.

The purpose of the present paper is to discuss the dynamic of stock trade in the context of this neuroeconomic decision-making model in the attempt to gain knowledge about the cycling of stability of the financial market. For such a purpose, the concept of anchored prices was incorporated into the model, and data from the New York Stock Market between January, 2, 2007 and July, 30, 2010 were used to study and to model the evolution of trading during a period of increasing (*bull market*) followed by a period of falling prices (*bear market*) that characterized the 2008 financial crisis.

2. Risk and Benefit evaluations

fMRI studies have been shown that financial decision-making involves widely neural distributed circuits (Fig. 2) with neurons located at the Orbitofrontal Cortex. Medialprefrontal cortex; Anterior Cingulate Cortex; Amigalda; Insula; Nucleus Accumbens, Superior Temporal Cortex; Fusiform Gyrus, etc. (e.g., Breiter et al, 2001; Kuhnen and Knutson, 2005; Knuston et al, 2003; 2007; Paulus et al, 2002; Paulus and Frank, 2006) and involved with the evaluation of risk and benefits of the decision to be make.

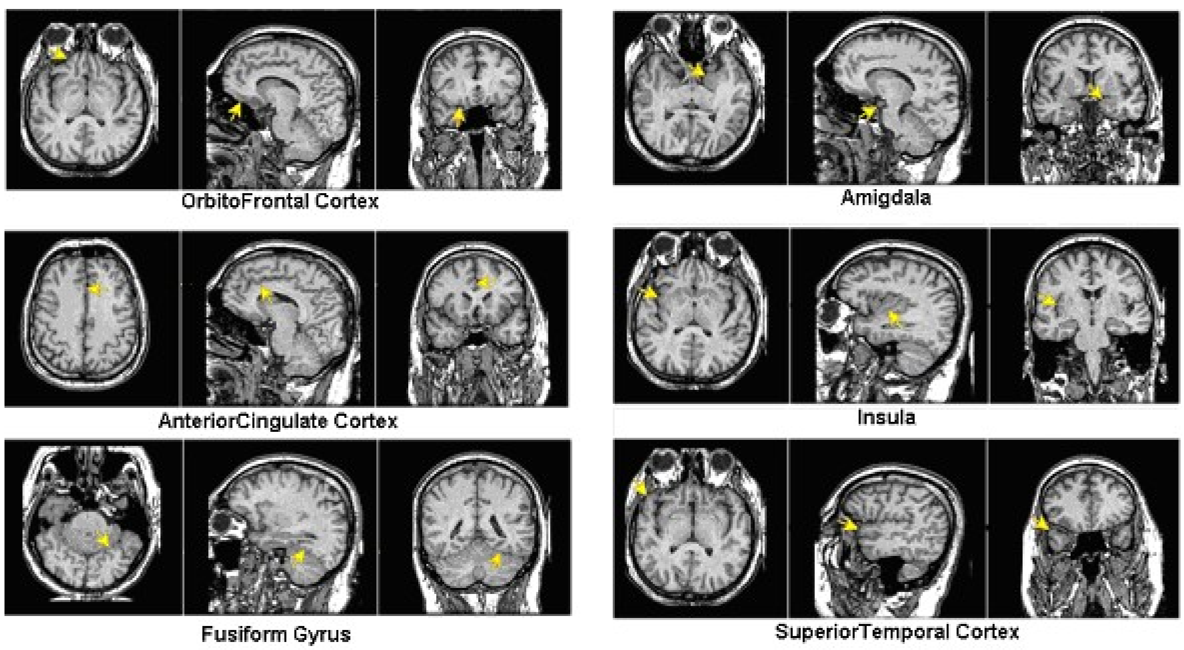

Figure 2 – Magnetic Resonance Images showing some of the neural structures discussed in the text.

In economy risk is in general associated with event uncertainty and it is assumed to be a function of event probability. However, recent papers are questioning this view and stressing that risk perception has both qualitative and quantitative components (e.g., Fellner and Maciejvsky 2007; Vorhold et al, 2007;). Nature shaped the brain to calculate risk in conditions that information about event uncertainty is scarce and the opportunity for complex analytical analysis is null. Nature shaped serotoninergic circuits to calculated risk taking into account any knowledge animals may have about the course of possible actions (Coates. and Herbert, 2008; Graeff, 2003; Huettel et al, 2006; O'Doherty et al, 2001; Kuhnen and Knuston, 2005; Ledoux, 1996; Paulus et al, 2002). In the same way, expected benefits are calculated by dopaminergic circuits taking into account previous acquired knowledge about rewards associated with action implementation (Gehring and. Willoughby, 2002; Knutson, et al, 2003; O'Doherty et al, 2001; Preuschoff, K, P. Bossaerts and Quartz, S. R. (2006) Neural; Schultz, 2004).

3. Willingness to buy or sell

Considering the above assumptions, it is proposed here that the dynamics of expected reward, ER, is tightly correlated with DA release and reuptake in the reward neural circuits, and the dynamics of calculated risk, CR is tightly correlated with the 5HT release and reuptake in the fear neural systems. Because of the dependence of the expected reward and the calculated risk on the release and reuptake of neuromodulators, the actual values of both the expected reward and calculated risk are dependent on two types of functions: assessment functions modeling the neuromodulator release and discounting functions modeling the neuromodulator reuptake.

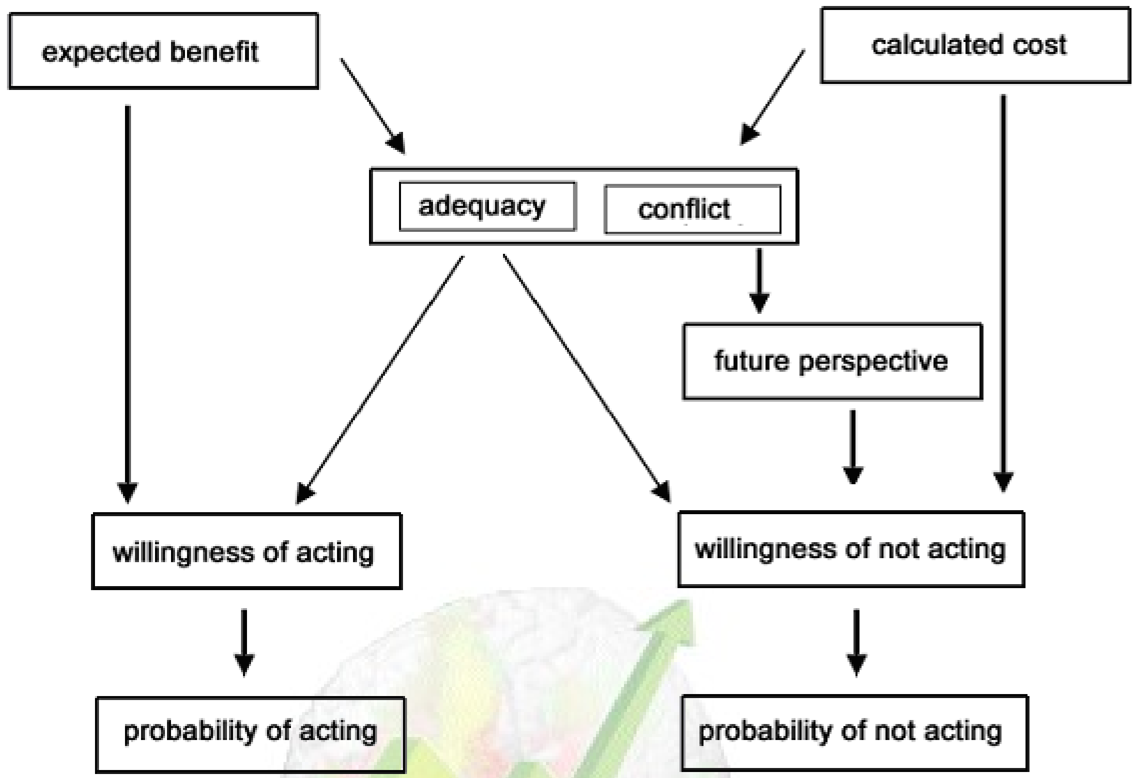

Figure 3. The structure of the decision making model

Expected benefit and calculated cost for a given action determines the degree of conflict for decision making and its adequacy for fulfilling a given necessity. The degree of conflict sets the time allocation or future perspective for implementing the action. The *willingness* of implementing the action as the problem solution is determined by its expected benefit and adequacy as well as by the future perspective of this implementation. The *willingness* of not implementing the action as the problem solution is determined by its calculated cost and future perspective and inversely correlated with its adequacy See the text for further details.

As a consequence, the *willingness* W to implement an action a_i is calculated by taking into consideration its calculated risk CR and its expected reward ER. Figure 3 display the structure of the model to be discussed in what follows. In a first approximation it may be supposed that the willingness to act increases as the expected reward surpass the calculated risk (ER>CR) and the willingness not to act increases when the opposite is true (ER<CR). However as the estimated values of reward and risk become similar (ER $\approx$ CR) a conflict, C, arises making decision hard. In addition this conflict decreases as either ER or CR tend to zero. Therefore, W is modulated by the conflict C generated by ER and CR because the cognitive effort, E for deciding about a_i increases with C (Botvinick, Cohen and Carter, 2004).

Two aspects of future thinking influences decision making (Fellow and Farah, 2005): the first concerns how steeply rewards are devalued as their delivery is pushed into the future, a phenomenon known as temporal discounting, while the second concerns the perceived dimensions of future time, sometimes labeled 'future time perspective'. Although these two aspects of future thinking seem similar, they are not equivalent. Future time perspective measures a spontaneously chosen time horizon, which would not necessarily affect the way a person evaluates an event at a specific time in the future when explicitly cued to do so. Similarly, the rate at which reward decays across a specified delay may differ across individuals, even if they have a similar future time perspective (Fellow and Farah, 2005). Here, the possible *time allocation* (or future perspective), TA for deciding about a_i is assumed to be dependent on C. In this context, the willingness to act W is also dependent on TA.

In this context, the *adequacy* of action a_i is proposed to be calculated as:

$$\text{adequacy} = 1 - \frac{\text{calculated cost}}{\text{expected benefit} + \text{calculated cost}}$$

because the *adequacy* $\Psi_{a_i}(t)$ is assumed to increase as the cost/benefit increases.

From the above, it is proposed that:

a) the willingness to implement W action a_i (to buy or to sell) is proposed to increases with the expected benefit, the adequacy and the future perspective of acting, that it is:

$$\text{wilingness to act} = \text{expected benefit} * \text{adequacy} * \text{future perspective}$$

b) and the willingness to avoid implementing the action a_i (to buy or to sell) is proposed to increase with the calculated cost and the future perspective TA of acting and to decrease with the adequacy of a_i, that is

$$\text{wilingness not to act} = \frac{\text{calculated cost} * \text{future perspective}}{\text{adequacy}}$$

Finally the probability of implementing a_i and the probability of not implementing a_i are obtained as:

$$\text{probability of acting} = \frac{\text{willingness to act}}{\text{willingness to act} + \text{willing not to act}}$$

and

$$\text{probability of not acting} = \frac{\text{willingness not to act}}{\text{willingness to act} + \text{willing not to act}}$$

4 The investor´s humor

A *bull market* it is defined here when the willingness to buy s_i it is greater than the willingness to sell it, and the price is set by the seller. A *bear market* is defined when the opposite is true and the price is set by the buyer. Therefore, market evolution is dependent on the investor's humor, and we propose, here, it to be dependent on both the conflict about buying or selling the stock s_i and the stock volatility. In other words:

$$\text{investor's humor} = f(\mathit{conflict}, \mathit{volatility})$$

If the benefit in buying or selling a stock is much greater the cost or risk of the trade then investor's humor must be positive and proportional to the expected benefit and inversely related to the conflict experienced in thetransaction. If the cost or risk of buying or selling a stock is much greater than the benefit of the trade then investor's humor must be negative and proportional to the conflict. In the same line of reasoning, if volatility is high but positive then humor must be positive and proportional to it since great profits may be expected. On the contrary, if volatility is high and negative then humor must be negative and proportional to it since great losses may be expected.

5 The prices for next day

Because uncertainty about market evolution is in general high, there is no way the stock price can be know for sure, despite the proposal of the Fundamentalist Theory. Does not matter the economical analysis to calculate the expected return or the calculated risk or cost, these values will be psychologically recoded according to the psychophysics rules, into a low…high scale, to determine the degree of activation of the pleasure and fear neural circuits. These neural values will be used to determine the perceived benefit and risk, as well as the conflict associated to the trade. In other words:

$$\text{perceived benefit} = \mathit{filtered}(\mathit{return}) \text{ and } \text{perceived risk} = \mathit{filtered}(\cos t)$$

These values will determine the willingness to buy or sell the stock s_i as well as the conflict and the adequacy in trading s_i. Therefore, the trading prices are assumed, here, to be dependent on these evaluations.

Another key assumption, here, is that if humor is positive then investors are willing to buy and not to sell the stock s_i, on the contrary if humor is negative the market tend to be a *bear market*. Therefore, the prices will be considered to go up if humor is positive and to go down if negative. Naturally, the humor polarity depends on the investor emotional threshold that varies for different people and can be adjusted to different market conditions. In other words:

$$\text{humor} > 0 \text{ if } f(\mathit{conflict}, \mathit{volatility}) > \mathit{emotional} \text{ threshold, otherwise} < 0$$

Price adequacy is another psychological function of actual values (see Anchoring Prices in this site). The adequacy of the actual stock price is proposed here to be

$$\text{price adequacy} = \mathit{filtered}(\mathit{price})$$

From the above, we propose there that the acceptable price variation for the next day is

$$\text{acceptable price variation} = f(\mathit{priceadequacy}, \mathit{humor})$$

In this context, the price of next day it is calculated as the price of today plus the acceptable variation. In other words:

$$\text{price next day} = \text{price today} + \text{acceptable price variation}$$

6 Dow Jones Indes: 82 years of history

Figure 4 shows the real Dow Jones Index evolution from October, 1928 to July, 2010 and the same index calculated according to model proposed, here, assuming

$$\text{price day d} = \text{price day d - 1} + \text{acceptable price variation}$$

with day 1 equal to 10/01/1928. Adjustments of the emotional threshold and the constants in price adequacy function were made, to accommodate the distinct periods of *bull* and *bear markets* as well as the growth of the Dow Index from smaller than 100 points in 1929 to almost 15000 in 2008.

The results show that the model proposed here nicely fit 82 years of history of the Down Jones Index with a high accuracy, such that we may conclude that this model provides an interesting description of the stock market, that deserves future developments and testing.

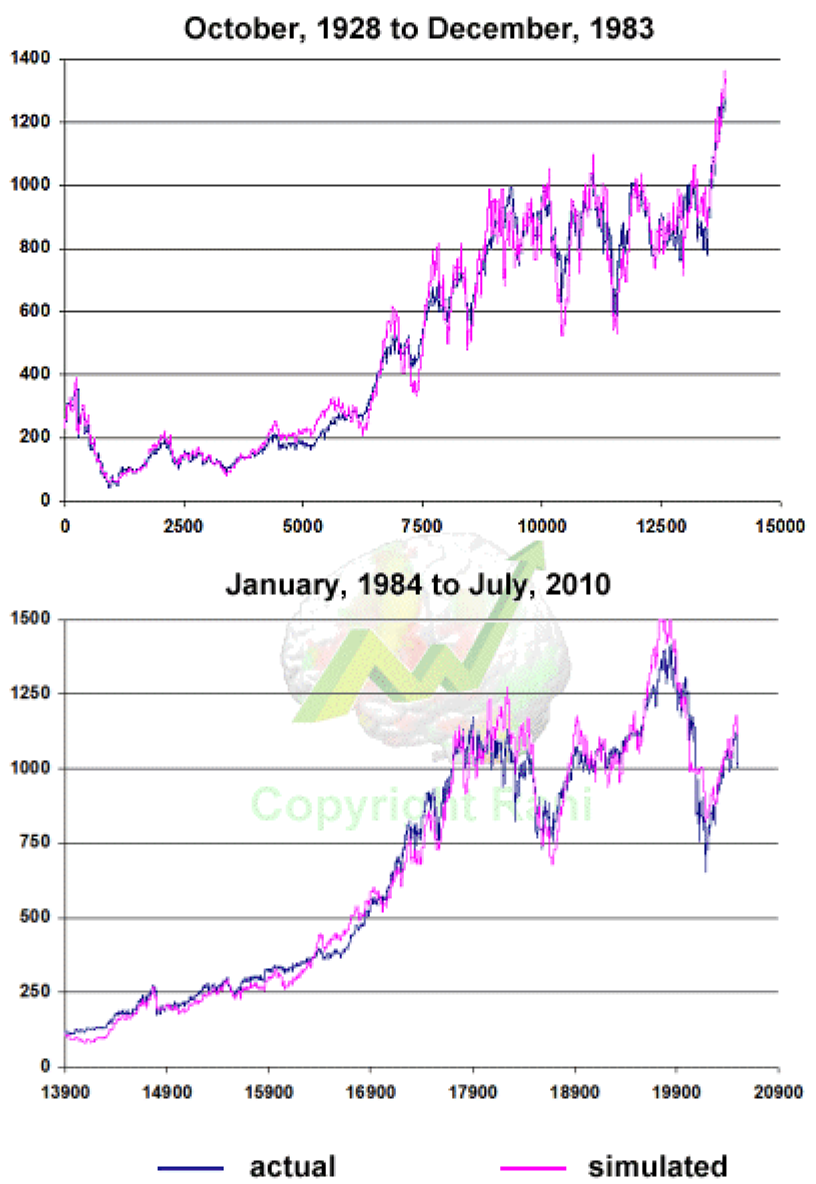

Figure 4 – Dow Jones Indes: 82 years of history

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eq. 1: $\Delta_{s_i}(n) = p_{s_i}^{v}(n) - p_{s_i}^{c}(n)$

eq. 2: $\kappa_0(n) = a - b * \Delta_{s_i}(n)$

eq. 3: $\bar{\Delta}_{s_i}(n) = \dfrac{\Delta_{s_i}(n)(n)^{\kappa_0(n)}}{\Delta_{s_i}(n)^{\kappa_0(n)} + \left(\theta_{a_i} - \Delta_{s_i}(n)\right)^{\kappa_0(n)}}$

eq. 4: $p_{s_i}^{f}(n) = (1 + a)\bar{\Delta}_{s_i}(n)$

eq. 5: $r_{s_i}(n) = \dfrac{at_c(n)}{p_{s_i}(n)N_i(n)}$

eq. 6: $c_{s_i}(n) = \dfrac{de_c(n)}{n_i(n)}$

eq. 7: $\lambda_{s_i}(n) = \beta_{s_i}^{\frac{1}{\kappa_0 \, s_i(n)}}$

eq. 8: $\chi_{s_i}(n) = \dfrac{c_{s_i}(n)^{\kappa_0/3}}{c_{s_i}(n)^{\kappa_0/3} + \left(\theta_{a_i} - c_{s_i}(n)\right)^{\kappa_0/3}}$

eq. 9: $\Psi_{s_i}(n) = \dfrac{\rho_{s_i}(n)\lambda_{s_i}(n)}{\lambda_{s_i}(n) + \chi_{s_i}(n)}$

eq. 10: se $a_{s_i}(t) > 0$ $\rho_{s_i}(n) = ka_{s_i}(t)m_{s_i}(t)$

caso contrario $\rho_{s_i}(n) = 1 - ka_{s_i}(t)m_{s_i}(t)$

eq. 11: $\varsigma_{s_i}(n) = -\bar{\lambda}_{s_i}(n)\log_2 \bar{\lambda}_{s_i}(n) - \bar{\chi}_{s_i}(n)\log_2 \bar{\chi}_{s_i}(n)$, $\bar{\lambda}_{a_i} = \dfrac{\lambda_{a_i}}{\lambda_{a_i} + \chi_{a_i}}$, $\bar{\chi}_{a_i} = \dfrac{\chi_{a_i}}{\lambda_{a_i} + \chi_{a_i}}$

eq. 12: $e_{s_i}(n) = 1 - \varsigma_{s_i}(n)$

eq. 13: $\mu_{s_i}(n) = \lambda_{s_i}(n)e_{s_i}(n)\psi_{s_i}(n)$, $\mu_{\sim s_i}(n) = \xi_{s_i}(n)e_{s_i}(n)/(1 + \psi_{s_i}(n))$

eq. 14: $P_{s_i}(n) = \dfrac{\mu_{s_i}(n)}{\mu_{s_i}(n) + \mu_{\sim s_i}(n)}$, $P_{\sim s_i}(t) = \dfrac{\mu_{\sim s_i}(n)}{\mu_{s_i}(n) + \mu_{\sim s_i}(n)}$

eq. 15: *se* $\varsigma_{s_i}(t) > \alpha_m$ *então* $m_{s_i}(t) = \bar{\Delta}_{s_i}(t)p_{s_i}^{v}(t)$

caso contrário $m_{s_i}(t) = \bar{\Delta}_{s_i}(t)p_{s_i}^{c}(t)$, $\alpha_m = \bar{\varsigma}_{s_i}(t)$, $\bar{\varsigma}_{s_i}(t) = \dfrac{\sum_{i=1}^{m} \varsigma_{s_i}(t)}{m}$

eq. 16: $a_{s_i}(t) = (\alpha_h - \varsigma_{s_i}(t) + \xi$, $\alpha_h = a_h + b_h\kappa_0(t)$

eq. 17: $p_{s_i}^{f}(t+1) = p_{s_i}^{f}(t) + \mathrm{K}(t)a_{s_i}(t)P_{z_i}(t)m_{s_i}(t)$, $\mathrm{K} = a_a + b_a\kappa_0(t)$