# 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. 1 shows the evolution of the mean $\bar{p}^{c}_{s_i}(n)$ prices of 250 stocks traded at Bovespa (The Brazilian Stock Market) during the year of 2008 (248 trading days), and illustrates this oscillatory behavior of the financial market.



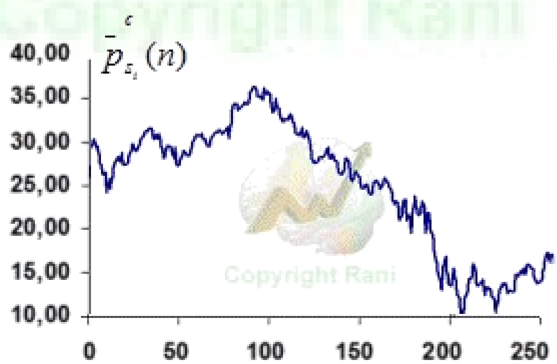


**Figure 1 The evolution of the stock mean price at Bovespa during 2008**

The actual stocked market behavior is in sharp contrast with the academic models for financial decision-making such as the Theory of Market Efficiency, the Modern Theory of Portfolio Allocation, etc. (Block and Hirt, 2000; Melicher and Norton, 2007) that do not provide a adequate modeling of the large stock prices oscillations. Behavioral Finances has being shown that actual finance theories so far interpret the market as reflecting actions taken by rational managers in response to irrationality on the part of investors (Barberis and Thaller, 2005). Investors are not always rational in their financial decisions (e.g., Kuhen and Knutson, 2005; Felnner and Maciejvsky ; Sanfey et al, 2006; Huettel et al, 2006), that it is, they do not always try to maximize their profits (Sanfey et al, 2006). The role played by emotion in decision-making is proposed to explain the *irrationality* of the investors decision (e.g., Bernenhim and Rangel, 2004; Camerer et al, 2005; Loewentein et al., 2001). It has being proposed (e.g. Kahneman and Tversky, 1979) that investors are risk seeking in case of losses and risk avoiding in case of gains. As a matter of fact, it is a Darwinian rule of evolution that the chances of survival of any animal it linked to his ability to obtain more energy from food than the energetic cost of obtaining it. Nature shaped animals to be profit seeking and risk or loss avoiding.

*Market Sentiment* (MS) is the expression used to define the emotional state of the financial market and it is supposed to influence the stock price. MS is assumed to be dependent on data about the market, on government decisions, national and international events, contagion, etc. A *bull market* is associated with increases of the investor's trust and motivates buying in anticipation of expected good revenues, future stock price increases, etc. A *bear market* is characterized by high pessimism and motivates selling in anticipation of future losses. MS is supposed to synchronize investor behavior and to promote *herding* during financial crisis (e.g., Hwang, S. and M. Salmon, 2004; Ushida and Nakagawa, 2007; Tam et al, 2008).

The evolution of brain mapping techniques in the last decades paved the way for investigating the brain activity associated with human decision-making, and Neuroeconomics started as a multidisciplinary endeavor aiming to apply Neuroscience technology and knowledge to investigate and better understand models and theories proposed by Economy (e.g., Gehring and Willoughby, 2002; Huettel, et al, 2006; King-Casas et al, 2005; KuhnenAnd Knuston, 2005; Knutson et al, 2003; O´Doherty et al, 2001; Preuschoff, Bossaerts and Quartz, 2006; Rocha, Rocha and Massad, 2009; Sanfey et al, 2006; Tobler et al, 2007; Vorhold et al, 2007).

Tremblay and Schultz (1999) delivered three types of juices to thirsty monkeys and recorded frontal-orbital neurons that encoded juice preference and proposed that these neurons encoded the relative juice utility.  However, Padoa-Schioppa and Assad (2006) have shown that other neurons in the frontal-orbital cortex encode the cardinal utility of the juices offered to their thirsty monkeys. Multiple representations of value exit in the primate brain (Plat and Padoa-Schioppa, 2009) such that absolute and relative utilities are handled by different neurons and dependent on learning. Experience allows cardinal utility to be engraved in brain, whereas relative preferences anchored on previous knowledge or established rules are used in uncertain environment or conditions. Seymour and McClure (2008) recently reviewed the Neuroeconomic literature that it is showing that people are very susceptible to manipulation of their price expectancies and evaluations whenever experience did not fixed cardinal utility evaluation.

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 propose 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 $c_j$.



The purpose of the present paper is to study the price anchorage of trading of 250 stocks at Bovespa (São Paulo Stock Market) during the year of 2008.

## 2. Trading at Bovespa

Fundamental economic data and stock prices for 250 companies trading at Bovespa at the site http://www.bovespa.com.br/Principal.asp. The analysis of datashows that

$$p_{s_i}^{b}(n) < p_{s_i}^{c}(n) < p_{s_i}^{s}(n),$$

because

$$\Delta^{b}_{s_i}(n) = p_{s_i}^{c}(n) - p_{s_i}^{b}(n) > 0 \text{ and } \Delta^{s}_{s_i}(n) = p_{s_i}^{s}(n) - p_{s_i}^{f}(n) > 0$$

for the entire year, as shown in Fig. 2. Actually, the mean value of $\Delta^{b}_{s_i}(n)$ was $\overline{\Delta}^{b}_{s_i}(n) = .64 \pm 0.34$ and that of $\Delta^{s}_{s_i}(n)$ was $\overline{\Delta}^{s}_{s_i}(n) = 0.29 \pm 0.21$, showing that $p_{s_i}^{c}(n)$ was closer to $p_{s_i}^{c}(n)$ than to $p_{s_i}^{b}(n)$.

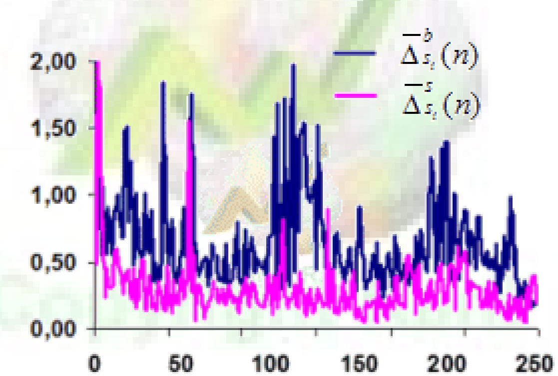


**Fig. 2 – The evolution of $\Delta^{b}_{s_i}(n)$ and $\Delta^{s}_{s_i}(n)$ during 2008**

The statistical analysis of the relations between $\Delta^{b}_{s_i}(n)$, $\Delta^{s}_{s_i}(n)$ and $p_{s_i}^{c}(n)$ showed that a linear relation between $\log(\Delta^{b}_{s_i}(n))$ or $\log(\Delta^{s}_{s_i}(n))$ and

$\log(p^{c}_{s_i}(n))$ explains around 50% ( $R^2 \cong 0.5$ ) of data variance (Fig. 3). These results confirms that the psychological evaluation of the acceptance $\psi^{b}_{s_i}(n)$ ( or $\psi^{s}_{s_i}(n)$ ) of the stock price difference $\Delta^{b}_{s_i}(n)$ ( or $\Delta^{s}_{s_i}(n)$ ) is governed by the rules of psychophysics that establish a non linear relation between $\Delta^{b}_{s_i}(n)$ or $\Delta^{s}_{s_i}(n)$ and $p^{c}_{s_i}(n)$ (e.g., Bernasconi et al, 2008; Stewart et al, 2005). Because of this, it is proposed here that

$$\psi^{b}_{s_i}(n) = \frac{\Delta^{b}_{s_i}(n)^{\kappa_o(n)}}{\Delta^{b}_{s_i}(n)^{\kappa_o(n)} + \left(\theta - \Delta^{b}_{s_i}(n)\right)^{\kappa_o(n)}}$$

$$\psi^{s}_{s_i}(n) = \frac{\Delta^{s}_{s_i}(n)^{\kappa_o(n)}}{\Delta^{s}_{s_i}(n)^{\kappa_o(n)} + \left(\theta - \Delta^{s}_{s_i}(n)\right)^{\kappa_o(n)}} \qquad (1)$$

where $\theta$ it is a scalling factor and $0 < \kappa_o(n) < 1$ it is a constant to be experimentally calculated and it is called here acceptance sensibility.

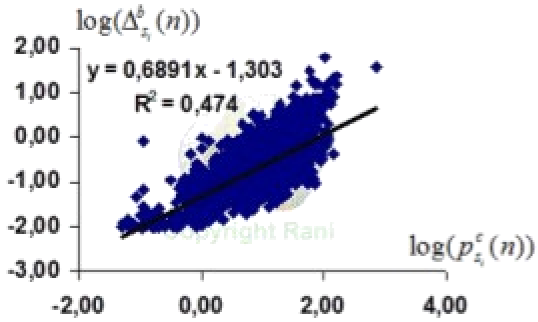


**Figure 3 – Non linear relation between $p^c_{s_i}(n)$ and $\Delta^b_{s_i}(n)$**

In this context, it is possible to assume that the maximum value $\bar{p}^b_{s_i}(n)$ the buyer is *willing to pay* is

$$\bar{p}^b_{s_i}(n) = (1+\psi^b_{s_i}(n))p^s_{s_i}(n) \tag{2a}$$

and the minimum value $\bar{p}^s_{s_i}(n)$ the seller is *willing to receive* is

$$\bar{p}^s_{s_i}(n) = (1-\psi^s_{s_i}(n))p^b_{s_i}(n) \tag{2b}$$

such that, the trade occurs if they agree about closing price $p^c_{s_i}(n)$ such that

$$\bar{p}^s_{s_i}(n) \le p^c_{s_i}(n) \le \bar{p}^b_{s_i}(n) \tag{2c}$$

in the case of *bull market* or at least

$$p^c_{s_i}(n) \le \bar{p}^b_{s_i}(n) \tag{2d}$$

in the case of *bear market*.

In order to experimentally adjust these constants, data from January trading were used. Different values of $\kappa_o(n)$ were tested until the smallest pair of values for $\Delta^b_{s_i}(n)$ and $\Delta^s_{s_i}(n)$ was obtained. The values for $\theta$ were determined taking into account the smallest value of $\Delta^b_{s_i}(n)$ and $\Delta^s_{s_i}(n)$ to make $\left(\theta - \Delta^b_{s_i}(n)\right)$ and $\left(\theta - \Delta^s_{s_i}(n)\right)$ always positive. The statistical analysis showed that these $\kappa_o(n)$ were linearly correlated with $\Delta^b_{s_i}(n)$ or $\Delta^s_{s_i}(n)$ such that the functions

$$\kappa_o(n) = 0.50 - 0.20\Delta^b_{s_i}(n)) \qquad (3a)$$



or

$$\kappa_o(n) = 0.45 - 0.18\Delta^s_{s_i}(n)) \qquad (3b)$$

accounted for around 75% ( $R^2 = .78$ for eq. 3a and $R^2 = .72$ for eq. 3b) of data variance. Equation 3a was used to calculate $\kappa_o(n)$ all 2008 trading days in order to compute $\bar{p}^{b}_{s_i}(n)$ and $\bar{p}^{s}_{s_i}(n)$ in Eqs. 2. Figure 4 shows the results of these simulations.

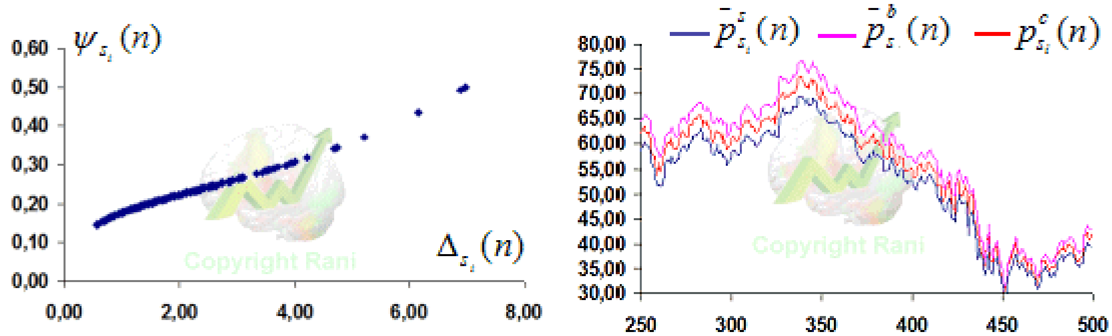


**Figure 4 – Calculating price adequacy**

The results in Fig. 4 show that the closing price $p^{c}_{s_i}(n)$ was in general smaller than the highest price $\bar{p}^{b}_{s_i}(n)$ the buyers were willing to pay because the mean value of $\bar{\Delta}^{b}_{s_i}(n)$ was $2.42 \pm .088$ . In contrast, $p^{c}_{s_i}(n)$ was greater than the smallest price $\bar{p}^{s}_{s_i}(n)$ the seller was willing to receive because $\bar{\Delta}^{s}_{s_i}(n) = 2{,}57 \pm .85$ ). Both $\bar{\Delta}^{b}_{s_i}(n)$ and $\bar{\Delta}^{s}_{s_i}(n)$ decreased during the 2008 crisis in comparison to the preceding period, showing that during a *bear market* traders stick harder to their price offers than during a *bull market.*

## 3. Conclusion

The analysis of price evolution of 250 stocks traded at Bovespa during the year of 2008 showed that closing prices $p^c_{s_i}(n)$ are nicely described as a linear function of the selling $p^s_{s_i}(n)$ and buying $p^b_{s_i}(n)$ prices offers. The perceptions $\psi^b_{s_i}(n)$ and $\psi^s_{s_i}(n)$ of the adequacy of the buying and selling prices offers is nicely described by the psychophysics laws. Trading is requires the closing price to $p^c_{s_i}(n)$ to be bounded by the maximum value $\bar{p}^b_{s_i}(n)$ the buyer is *willing to pay* and the the minimum value $\bar{p}^s_{s_i}(n)$ the seller is *willing to receive* . In a *bear market* these prices come closer than in a *bull market*.

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