Neuroeconomics of Asset-Price Bubbles: Toward the Prediction and Prevention of Major Bubbles

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Abstract

Asset-price bubbles challenge the explanatory and predictive power of standard economic theory, suggesting that neuroeconomic measures should be explored as a potential way to improve the predictive power of standard theory. We begin this exploration by reviewing results from functional magnetic resonance imaging (fMRI) studies of lab asset-price bubbles and herding behavior (i.e., following others' decisions). These results are consistent with a neuroeconomics-based hypothesis of asset-price bubbles. In this view, decision making during bubble or non-bubble periods of financial-market activity is driven by, respectively, evolutionarily ancient or new neurocircuitry. Neuroimaging studies that test this or other neuroeconomics-based hypotheses of asset-price bubbles may yield a bubble-related biomarker (e.g., low trade-related lateral neocortical activity associated with traders’ herding-based decisions). Wearable functional near-infrared spectroscopy (fNIRS) technology could determine the prevalence of such a biomarker among financial-market participants, thereby enabling the real-time detection of an emerging bubble. We describe mechanisms by which this early-warning signal could be exploited in self-regulatory or government-administered policies for financial-system stabilization. In summary, neuroimaging-based financial-system regulation may be useful for distinguishing bubbles from non-bubble periods and preventing major asset-price bubbles.

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I. Introduction

It is not as if economic theory has given us the final word on...business cycle and stock market fluctuations. It is hard to believe that a growing familiarity with brain functioning will not lead to better theories for these and other economic domains, perhaps surprisingly soon.

Colin F. Camerer, George Loewenstein, and Drazen Prelec (2004, p. 573)

Not every puzzle can be solved in the course of normal science; such cases are anomalies. Crisis occurs when a sufficient weight of particularly significant anomalies causes scientists to question the capacity of the current tradition to solve those anomalous puzzles.

Alexander Bird (2012, p. 861, italics in original)

Econometric methodology encounters difficulties in identifying asset-price bubbles retroactively, let alone in real time (Balke and Wohar, 2009). This difficulty may result from econometricians assigning themselves the hapless task of measuring only external variables when assessing group-level effects (i.e., asset-price bubbles) that arise partly from internal, neuroeconomic processes. The largely missed opportunity to forecast the recent financial-system crisis has led to calls for new macroeconomic theory and methodology (Colander et al., 2009; Stiglitz, 2011, 2014). For example, Janet L. Yellen (2010, p. 243), in a “Closing Panel Presentation” before she became the Chairwoman of the Board of Governors of the Federal Reserve System, questioned the “relevance and usefulness” of the “dynamic stochastic general equilibrium model with nominal rigidities”, which is a model that “ascended to the position of reigning macroeconomic orthodoxy.” From the perspectives of traditional econometrics and macroeconomics, asset-price bubbles could be viewed as unsolved anomalies due to the above analytical and forecasting difficulties. Neuroeconomists now have an opportunity to step into this analytical void left by traditional econometric and macroeconomic approaches. The present review article will assess whether new applications of neuroeconomic methods, in an approach that could be called “neuroeconometrics”, may be useful for detecting the emergence of asset-price bubbles.

Early concerns about herding (i.e., decision-making that follows the decisions of others) by William Stanley Jevons, who wrote in The Theory of Political Economy (1871; quoted by De Bondt [2012]) “…as a general rule, it is foolish to do just what other people are doing, because there are almost sure to be too many people doing the same thing”, have been echoed recently due to the potential of herding to destabilize financial markets and yield asset-price bubbles or crashes (Scharfstein and Stein, 1990; Baddeley, 2010; Stiglitz, 2011; Bursztyn et al., 2014). Therefore, neuroimaging signs of herding may be candidate neuroeconometric indicators for an emerging bubble. A high prevalence of these early-warning indicators among market participants could signal regulators to prevent major bubbles and crashes by implementing countercyclical measures (e.g., adjusting caps on loan-to-value ratios for mortgages and increasing capital requirements for banks [Evans, 2011; Bernanke, 2012]). On a voluntary basis, these warning signals also could be used by market participants to trigger self-regulatory actions. To facilitate the development of this neuroimaging-based regulatory approach, we propose a research program that seeks neuroimaging signs of herding associated with decision-making by financial-market participants. Herding-related decisions are hypothesized to drive the emergence of asset-price bubbles, whereas deliberative financial decision-making may be more prevalent during non-bubble periods of financial-market activity.
The remainder of the present review article is organized as follows. The following section discusses the distinction between deliberation and herding, while reviewing studies of neural bases for these types of decision making. The section concludes by showing that the neural bases of deliberation and herding provisionally support a novel neuroeconomics-based hypothesis of asset-price bubbles. Section III discusses alternative neuroeconomics-based hypotheses of asset-price bubbles. Sections IV and V, respectively, propose roles for neuroeconomics research in developing self-regulatory or government-administered policies for financial-system stabilization. Section VI introduces neuroeconometrics as a field for studying and applying neuroeconomic measures in the analysis of macroeconomic or financial-market processes. Section VII concludes by emphasizing the welfare effects of elucidating potential neuroeconomic mechanisms underlying asset-price bubbles.

II. Deliberation vs. herding

...humans may use the same neural machinery to surf the stock exchange that they once used to scavenge the savannah.

Brian Knutson and Peter Bossaerts (2007, p. 8176)

A. Deliberation

Deliberation can include both quantitative, technical analysis and a more qualitative “gist” associated with intuition (Reyna and Huettel, 2014). Experts, even in quantitative fields, rely on intuition (Bird, 2012; Reyna, 2012). For example, studies of financial-market traders show their use of intuition rather than pure technical ability (Fenton-O’Creery et al., 2005). Lateral neocortical brain regions, particularly lateral prefrontal cortex (PFC) and parietal cortex, show activations in fMRI studies of calculation (Corricelli and Nagel, 2009; Shirer et al., 2012) and gist-related intuition (Reyna and Huettel, 2014). A quantitative meta-analysis of 28 fMRI or positron emission tomography (PET) studies showed predominantly neocortical activations during subjects’ deductive reasoning, which was based on relational, categorical, or propositional arguments (Prado et al., 2011). Brain regions most consistently activated during deductive reasoning included the middle frontal gyrus, inferior frontal gyrus, medial frontal gyrus, precentral gyrus, posterior parietal cortex, and basal ganglia. Intensive reasoning training strengthened fMRI-measured connectivity between lateral PFC and parietal cortex (Mackey et al., 2013).

Other deliberative processes associated with activations in lateral PFC and parietal cortex include the exploration of alternative options (Laureiro-Martinez et al., 2014), complex value processing that integrates multiple pieces of information (Dixon and Christoff, 2014), learning to make optimal investment choices (Rudorf et al., 2014), rule-based cognitive control (Dixon and Christoff, 2014), and making comparisons with reference to attributes such as size, numbers, line lengths, angles between lines, luminance, time, beverage taste, physical attractiveness, monetary rewards, and relations between stimuli (Wendelken et al., 2012; Bien and Sack, 2014; Genovesio et al., 2014; Kedia et al., 2014). The degree of frontoparietal activation correlates positively with the similarity of attributes being compared (Bien and Sack, 2014; Kedia et al., 2014) and the computational load imposed by informational uncertainty (Fan et al., 2014). This frontoparietal network, which may have evolved in foraging anthropoid primates to support general problem-solving in humans (Genovesio et al., 2014), can be hypothesized to become activated as asset values are explored and compared during the uncertain conditions of non-bubble periods in financial markets. In contrast,
asset-price bubbles may elicit choices that are believed by traders to be exploiting an upward price trend. Exploitative choices were found to be associated with activations in the hippocampus and medial PFC (Laureiro-Martinez et al., 2014). As noted below, studies of herding suggest that other non-neocortical areas besides the hippocampus may be activated during asset trading in bubble periods of financial-market activity.

B. Herding

Numerous authors in the fields of economics, social psychology, evolutionary biology, psychiatry, sociology, and political science have described herding as behavioral conformity that tends to be more reflexive than deliberative (Raafat et al., 2009; Morgan and Laland, 2012). As reviewed below, recent neuroimaging studies show a pattern of herding-related brain regional activations that could be exploited eventually for regulatory purposes.

There is nothing even remotely magical, mysteriously invisible, or perfectly efficient about the process that results in prices being more or less agreed to by market participants. This process is grounded in the decision-making (Authers, 2010) and valuation circuitry of the brain (Glimcher and Fehr, 2014), as shown increasingly by neuroeconomics laboratory research that models market-related activities (e.g., studies of “willingness to pay” [Plassmann et al., 2007]). During an asset-price bubble, market participants engaged in herding become willing to pay increasingly exorbitant prices for popular assets. This leads to a self-reinforcing acceleration of price increases.

Burke et al. (2010) applied fMRI to subjects during a stock-buying task with 3 phases: 1) computer-displayed stock return data had a high or low mean and a high or low variance; 2) four human or chimp faces were shown with their “buy” or “reject” decisions; 3) subjects made “buy” or “reject” decisions in alignment with or contrary to the social information in Phase 2. When this information consisted of 4 humans, but not chimps, buying, then financial herding (i.e., buying) was more likely in Phase 3 and social information-induced nucleus accumbens (NA) activation covaried with the degree of herd influence on decisions. During the decision phase (i.e., Phase 3), left amygdala activation occurred when decisions were aligned with those of humans, but not chimps (Burke et al., 2010). Anterior cingulate cortex was activated when decisions were contrary to those of humans, but not chimps.

Edelson et al. (2011) exposed subjects to 4 experimental phases: 1) they saw a filmed crime scene; 2) their memory of the scene was tested; 3) a subsequent memory test was preceded by co-observers giving false memory information and fMRI scans were done when subjects had a memory test that showed mostly socially induced memory conformity (i.e., herding); 4) a final memory test was preceded by revealing that co-observers’ information during Phase 3 was meaningless, so subjects either showed a reversion to their originally correct memory (i.e., a transient error) or they showed persistent errors associated with amygdala and hippocampal activations. Furthermore, social manipulation (i.e., co-observers reporting false memories) induced long-term memory conformity (i.e., herding or “persistent errors”) associated with increased hippocampal-amygdala connectivity (Edelson et al., 2011).

Zaki et al. (2011) had subjects rate the attractiveness of faces before learning how their peers rated each face. The subjects were then scanned using fMRI while they rated the faces a second time, when they showed herding (i.e., they changed their ratings to conform with peers’ ratings). This social influence also enhanced activity in NA and orbitofrontal cortex.
C. Deliberation and herding in a neuroeconomics-based hypothesis of asset-price bubbles

In summary, a neuroeconomics-based hypothesis of asset-price bubbles (Haracz, 2013) is tentatively supported by fMRI studies showing that herding-related decisions are associated with activations in evolutionarily ancient brain structures, such as NA (i.e., archistriatum; Klucharev et al., 2009; Burke et al., 2010; Zaki et al., 2011), hippocampus (i.e., archicortex; Edelson et al., 2011), and amygdala (Burke et al., 2010; Edelson et al., 2011), whereas deductive reasoning (Prado et al., 2011) or calculating (Corricelli and Nagel, 2009; Shirer et al., 2012) is more related to lateral neocortical activations. In this view, evolutionarily ancient or new neural circuitry (Cohen, 2005) may, respectively, drive decision making during bubble or non-bubble periods of financial market activity. A subset of neocortical areas (e.g., the medial prefrontal cortex [mPFC]) may be active during both bubble and non-bubble periods of market activity. Consistent with this proposal, the mPFC is involved in both fear expression (Etkin et al., 2011), which occurs during the bursting of a bubble, and mentalizing (e.g., developing a “theory of mind” about intentions of other market participants [Corricelli and Nagel, 2009; Bruguier et al., 2010; Zhu et al., 2012; De Martino et al., 2013; Hartwright et al., 2014]), which may be engaged during both bubble and non-bubble periods. Similarly, the involvement of ventromedial PFC in the predisposition to realize capital gains (Frydman et al., 2014) may occur during both bubble and non-bubble periods. Furthermore, the hippocampus is involved in deliberative decisions (Bornstein and Daw, 2013) and the NA participates in other financial decision-making processes besides herding (Lohrenz et al., 2007), so these structures may play roles in both bubble and non-bubble periods. Thus, the above neuroeconomics hypothesis of bubbles is best expressed in terms of a relative, rather than absolute, predominance of activations in evolutionarily ancient or new brain structures during, respectively, bubble or non-bubble periods of market activity. During a bubble, herding associated with excessive excitement (i.e., “animal spirits” [Akerlof and Shiller, 2009; Shiller, 2012]) among asset-trading or loan-making decision makers may represent a human counterpart to schools of fish, flocks of birds, and herds of other mammalian species. Markets, which are more efficient in non-bubble periods, may become inefficiently over-driven by behavior based on primitive or “rudimentary” (Bijleveld et al., 2012) brain mechanisms during bubble periods. Time-varying market efficiency is supported by mounting econometric evidence (Lim and Brooks, 2011), so neuroeconomic correlates, and potential causes, of this varying efficiency should be sought. Highly prevalent neuroimaging signs of herding among market participants may be an ancillary condition that casts suspicion on the choice situation (Bernheim and Rangel, 2008) and should alert regulators to mobilize countercyclical measures. The screening of market participants for such ancillary conditions may be done with fNIRS at less expense than fMRI (Cui et al., 2011; Bajaj et al., 2014; Holper et al., 2014; Kopton and Kenning, 2014; Piper et al., 2014; Scholkmann et al., 2014).

By testing this or other neuroeconomics-based hypotheses of asset-price bubbles, the research program outlined below (see Section IV) could eventually rise to the challenge put forth by, among others, Jeremy C. Stein (2013), who recently was a Member of the Board of Governors of the Federal Reserve System. This challenge is the development of a regulatory capacity to detect overheated financial markets in real time (Evanoff et al., 2012; Stein, 2013).

III. Alternative neuroeconomics-based hypotheses of asset-price bubbles

Camerer and colleagues emphasized theory-of-mind mechanisms underlying lab asset-price bubbles (De Martino et al., 2013). In their subjects exposed to replayed visual displays of lab-market bubbles, fMRI brain-scan activations were found in the mPFC, an area implicated in theory-of-mind
mechanisms, possibly reflecting subjects’ attempts to sense peers’ intentions (De Martino et al., 2013). Another fMRI lab-market study showed displays based on historical records of Lehman Brothers stock prices (Ogawa et al., 2014). Exposure to the Lehman Brothers bubble activated subjects’ inferior parietal lobule (IPL) and increased functional connectivity between dorsolateral PFC and IPL, possibly suggesting a more future-oriented mental focus during the bubble. These lab market studies may have limited external validity: fast-growing lab bubbles differ temporally from long-lasting real-world bubbles (e.g., the housing- and stock-market bubbles that rose and crashed during 2000-2008). Activations of neocortical areas occurred in the above studies of fast-growing lab bubbles. However, herding may be hypothesized to occur during prolonged real-world bubbles, in which case fMRI evidence for the involvement of evolutionarily ancient brain areas (e.g., NA, hippocampus, and amygdala) in various forms of herding, including that related to financial decision-making (Klucharev et al., 2009; Burke et al., 2010; Edelson et al., 2011; Zaki et al., 2011), could be informative for predicting bubbles. Crucially, the same choice (e.g., buying a stock) could be generated by herding-related neurocircuitry (see Sections II.B-C above) during bubbles, or by deliberative lateral neocortical circuitry (see Section II.A above) during non-bubble periods. Using wearable fNIRS technology (Shimokawa et al., 2009; Hofmann et al., 2014), it may be possible to identify herding behavior and thus predict bubbles. A field-experimental research program in real financial markets could test this hypothesis (see Section IV below).

The above fMRI studies of lab-market bubbles (De Martino et al., 2013; Ogawa et al., 2014) elicit concerns about external validity, due to: a) temporal factors (i.e., fast-growing lab bubbles vs. long-lasting real bubbles); b) asset prices that were unaffected by subjects’ trades, unlike the responsiveness of prices to trading in real financial markets. The latter caveat was addressed in a recent lab-market study, with trade-responsive prices, that yielded fMRI-measured NA activations (Smith et al., 2014), which, unlike the above-reviewed neocortical activations (De Martino et al., 2013; Ogawa et al., 2014), resembled results from fMRI studies of herding (Klucharev et al., 2009; Burke et al., 2010; Zaki et al., 2011). Smith et al. (2014, p. 10506) found “that tracking the group-defined bubble and committing to it in the form of increased brain-to-buying probability costs money. This defines a neural metric for irrational exuberance and measures it in terms of earnings.” The “neural metric” was NA activity that, when calculated as a moving average across all subjects, tracked bubble-related price changes and predicted crashes (Smith et al., 2014). This finding is an initial step toward a proof-of-concept for the presently proposed neuroimaging-based approach to financial-system regulation. Other fMRI studies of herding, involving financial (Burke et al., 2010) or non-financial (Klucharev et al., 2009; Edelson et al., 2011; Zaki et al., 2011) decision making, also found herding-related activations in non-neocortical areas (e.g., NA [Klucharev et al., 2009; Burke et al., 2010; Zaki et al., 2011], hippocampus [Edelson et al., 2011], and amygdala [Burke et al., 2010; Edelson et al., 2011]). Exceptions include herding-related activations in medial orbitofrontal cortex (Zaki et al., 2011) and posterior medial frontal cortex (Klucharev et al., 2009).

IV. Neuroeconomics in a Self-Regulatory Financial-System Stabilization Policy

The presently proposed neuroeconomics-based hypothesis of asset-price bubbles (see Sections II.C and III above) could be tested by applying fNIRS, which is an inexpensive, portable neuroimaging technology, to traders in financial markets on a voluntary basis (Haracz and Acland, 2014). Traders' fNIRS data could be collected in relation to the timing of mouse-clicks that initiate trades. The design of such a field experiment could be informed by initial lab-market fNIRS studies that may identify candidate neural markers of asset-price bubbles. Neural correlates of herding may be studied in lab asset-trading markets by manipulating asset values to elicit prolonged bubbles or
priming subjects with boom- or bust-related visual stimuli (Cohn et al., 2013). Subsequent field studies may reveal that traders show neural signs of herding during asset-price bubbles that later crash. The objective is to find a neural signature that enables the detection of a newly emerging bubble. This detection would enable traders to exit markets that appear over-heated, thereby preventing major bubbles and crashes. Taxpayer burden could be reduced under this financial-system regulatory method because many traders' preference to avoid bubbles may be sufficient to motivate their purchase of wearable neuroimaging technology. A target market for this technology could be the "average investors" recently described by Lewis (2014, p. 4): "He [the average investor] logs onto his TD Ameritrade or E*Trade or Schwab account, enters a ticker symbol of some stock, and clicks an icon that says 'Buy'...". These individual investors are prone to mistaken investment decisions (Barber and Odean, 2013) that may play a substantial role in the driving of asset-price bubbles (Griffin et al., 2011; Stein, 2013). Aggregating neuroimaging results across traders in an open-access format would enable neurofeedback (Greer et al., 2014; Kober et al., 2014; Robineau et al., 2014) at the population level. This non-intrusive, self-regulatory intervention to prevent or mitigate bubbles could potentially be implemented without government involvement. Traders could monitor a shared (Poline et al., 2012; Poldrack et al., 2013), open-access aggregated data stream of processed brain activity, collected from consenting traders’ wearable fNIRS technology (Kopton and Kenning, 2014; Piper et al., 2014). Real-time signs of over-heated markets (e.g., low levels of trade-related lateral neocortical activity) would warn traders to exit these markets and thereby prevent major bubbles voluntarily (Haracz and Acland, 2014). In this analysis of aggregated data, distributed computing could be used to find patterns (e.g., low trade-related lateral neocortical activity) in large data sets (Freeman et al., 2014). Participation in this bottom-up, as opposed to government-implemented, financial-system regulation could be encouraged by stripping all data of personally identifying information. Demographic data could be retained to seek a sample population that is representative of the overall investor population. The following section discusses an alternative, government-implemented policy of financial-system regulation based on this type of trade-related neuroimaging data.

V. Neuroeconomics in a Government-Administered Financial-System Stabilization Policy

The numbers of Americans who are in poverty, unemployed, and without health insurance increased after the financial-system meltdown in 2008 (Doty et al., 2011; Hoyanes et al., 2012; Bitler and Hoyanes, 2015), so these deleterious effects motivate a search for regulatory measures that could prevent financial-system crises and spillover macroeconomic effects. Econometric measures fail to detect reliably asset-price bubbles as they emerge, so the proposed research program will assess whether neuroeconomic measures may be useful for this purpose in screening that involves a representative sampling of market participants (see Section IV above). The aim is to find neuroimaging predictors (e.g., low trade-related lateral neocortical activity in aggregated data [see Section IV above]) of major changes in business cycles, including financial-system crises. As an alternative to the above self-regulatory policy (see Section IV above), these predictors could alert regulators to scrutinize relevant asset classes and implement countercyclical regulatory policies (e.g., raising down payment requirements for mortgages, increasing margins in stock purchases, tightening of lending standards, implementing or adjusting a financial transaction tax, increasing asset class-specific capital requirements for banks in ways that are tailored to systemic risks, and changing the size and composition of a more democratic central bank’s balance sheet [Evans 2011; Bernanke, 2012; Friedman, 2012; Stiglitz, 2012; Palley, in press]), thereby possibly curtailing the adverse health and socio-economic effects of prolonged recessions (Hoynes et al., 2012; Coile et al., 2014; Bitler and Hoyanes, 2015). The lack of such countercyclical measures to attenuate bubbles may be
facilitating cycles of repeated and intensified asset-price bubbles and crashes in the U.S. (Roubini, 2006). A neuroimaging-based financial-system regulatory mechanism may help to distinguish healthy (i.e., economically sound from a business-fundamentals standpoint) from unhealthy (e.g., herding-related) asset-price increases, the latter of which should trigger countercyclical measures. This distinction between economically sound and unsound asset-price increases is important from a regulatory perspective because, as noted by Charles L. Evans (2011, p. 5), President of the Federal Reserve Bank of Chicago, “…not all increases in asset prices represent departures from fundamentals…” The need for this distinction was underscored by Jeremy C. Stein (2014, p. 10), a recent Member of the Board of Governors of the Federal Reserve System: “…I would conjecture that it might be more normatively appropriate…to lean against a sharp reduction in risk premiums that is driven by investor sentiment rather than against one that is driven by a rational response to changes in the risk environment.” Risk premiums decline as asset prices rise, particularly during asset-price bubbles (Vogel, 2010). Market inefficiencies have become obvious after centuries of asset-price bubbles and crashes (Reinhart and Rogoff, 2009), so there is a clear need for regulatory measures that can detect unsound asset-price increases in real time.

The above self-regulatory (see Section IV) and government-administered financial-system stabilization policies are based on neuroeconomic measures that could be aggregated to assess group-level activity in financial markets. These measures function analogously to econometric measures of macroeconomic or financial-market processes. Therefore, the following section introduces the term “neuroeconometrics” to describe the study and application of these neuroeconomic measures that may be more properly called neuroeconometric measures.

VI. Neuroeconometrics

The rapid progress we are now seeing in neuroscience will likely yield new insights into the ambiguity, animal spirits, and caprice that Keynes and others since him have stressed.


After the stock-market crash in 1929, early econometricians hoped to develop methodology for taming the business cycle (Louca, 2007). Many decades later, econometricians have not developed methodology for reliably detecting asset-price bubbles (Gurkaynak, 2008; Balke and Wohar, 2009; Herwartz and Kholodilin, 2014). Camerer (2013) proposed that progress in explaining anomalies may accelerate if the unobserved variables in theories could be associated with areas of brain activity in neuroeconomic studies. Such studies also may help to estimate bias parameters (e.g., in models of overconfidence and overextrapolation of trends [Altì and Tetlock, 2014]). This neuroeconometric approach may improve our understanding of asset-price bubbles and other anomalies (Bird, 2012) that are not well explained or predicted by traditional econometric and macroeconomic approaches.

Another potentially fruitful starting point for neuroeconometrics could be to seek a neural basis for agent-based models of asset prices and bubbles (Cutler et al., 1990; De Long et al., 1990, Lux, 1995; Brock and Hommes, 1997; Chiarella and Di Guilmi, 2012; Chang, 2014; Shiller, 2014). These models typically assume that financial markets include heterogeneous agents with at least two belief types or levels of ability (e.g., “noise traders”, who believe that a trend will continue, or “rational arbitrageurs”, who believe that the asset price will eventually return to the fundamental value [Chang, 2014, p. 91]; “chartists” or “fundamentalists” [Chiarella and Di Guilmi, 2012, p. 8]; “feedback traders” or “fundamentals traders” [Cutler et al., 1990, p. 65]; “speculative investors” or
“fundamentalists” [Lux, 1995, p. 887]; “noise traders” or “sophisticated investors…who have rational expectations” [De Long et al., 1990, p. 707]; “naive” predictors or “sophisticated” predictors with “fundamentalist beliefs” [Brock and Hommes, 1997, p. 1063]; and “ordinary investors” influenced by “animal spirits” or “smart money investors” [Shiller, 2014, p. 1498]). A plausible working hypothesis, which could be tested with fNIRS in field studies of real financial markets, is that trend-following agents would show less trade-related activations in lateral neocortex than fundamentalist agents who use more deliberative trading strategies. An asset-price bubble may be indicated by a lowered prevalence of agents with activations in lateral neocortex.

The term “neuroeconometrics” could bring attention to the need within economics for a wide range of interdisciplinary measurement and analytical methodologies. This range may be usefully expanded to include internal, neuroeconometric measures because a growing body of evidence shows that increasing numbers of measured external variables does not improve forecasting (Fuentes et al., in press). Therefore, the examination of over 100 variables by central banks (Fuentes et al., in press) may be reaching a point of diminishing returns with regard to better forecasting results. A potential augmentation of econometrics by neuroeconomics, as proposed by Bernheim (2009, p. 8), may overcome this apparent impasse reached by solely relying on external variables: “…neural variables may well find their way into otherwise standard econometric analysis.” Other authors have also called for increased interactions between neuroeconomics and standard economic approaches (Caplin and Dean, 2007; Glimcher et al., 2007; Camerer, 2013).

A prominent central banker, namely Alan Greenspan (2008, pp. 521-523, italics added), former Chairman of the Federal Reserve Board, made comments that could be interpreted as a compelling, but unwitting, opening argument for extending risk-management and econometric modelers’ variables to include neuroeconometric measures: "I do not say that the current systems of risk management or econometric forecasting are not in large measure firmly rooted in the real world. ... But business-cycle and financial models still do not adequately address the innate human responses that result in swings between euphoria and fear and repeat themselves generation after generation with little evidence of a learning curve. Asset-price bubbles build and burst today as they have since the early eighteenth century, when modern competitive markets evolved. To be sure, we tend to label such behavioral responses - what John Maynard Keynes called 'animal spirits' - as irrational. But forecasters' concerns should be not whether human response is rational or irrational, only that it is observable and systematic. This, to me, is the large missing 'explanatory variable' in both risk-management and macroeconomic models. Current practice is to take into account such behavioral responses through 'add factors.' That is, modelers tweak their equations. Add-factoring is an implicit recognition that models, as we presently employ them, are structurally deficient, but the practice does not sufficiently address the problem of the 'animal spirits' variable. ... Periodic surges of euphoria and fear are manifestations of deep-seated aspects of human nature, and realistically there is little that governments or central banks have been able to do to divert or defuse them."

In some cases, the above “add factors” described by Greenspan (2008, p. 522) may be “unobserved variables” (Camerer, 2013, p. 434) that could become more observable with neuroeconometric methodology. Neuroeconometrics may thereby become better equipped than current econometric and macroeconomic methodology to “address the problem of the ‘animal spirits’ variable.” (Greenspan, 2008, p. 522)

VII. Conclusion
The reviewed results from neuroimaging studies of herding- and deliberation-related decision making are consistent with a neuroeconomics hypothesis of asset-price bubbles (Haracz, 2013). In this view, evolutionarily ancient or new neurocircuitry, respectively, may drive decision making during bubble and non-bubble periods of financial-market activity. Biomarkers of asset-price bubbles (e.g., low trade-related lateral neocortical activity) may be yielded by a research program that applies fNIRS to lab-market subjects or traders in field studies of real financial markets. These biomarkers may enable the real-time detection of emerging bubbles and, thus, the prediction of major bubbles. Therefore, the proposed neuroeconomic basis of asset-price bubbles has implications for financial-system regulatory policy.

The above biomarkers could function as neuroeconometric signals of asset-price bubbles in self-regulatory or government-administered policies for financial-system stabilization. In a self-regulatory policy involving neurofeedback at the population level, bubble-related biomarkers in aggregated neural activity could warn traders to exit overheated markets, thereby preventing major bubbles voluntarily. This self-regulation can be understood as a policy tool that helps individuals to execute their stated preferences (Madrian, 2014) because traders generally prefer to avoid losing money in bubbles that crash. Alternatively, aggregated bubble-related biomarkers could alert government regulators to prevent major bubbles by implementing countercyclical measures (e.g., tightening of lending standards and elevating down payment requirements for mortgages). This government-administered policy represents the more traditional approach of using mandates as policy tools (Madrian, 2014).

Neuroeconomics offers researchers and policymakers a fresh approach to studying and mitigating asset-price bubbles. The policy implications of potential neuroeconomic mechanisms underlying bubbles deserve increased attention because the bursting of bubbles in financial markets can have widespread adverse effects throughout society (e.g., prolonged recessions [Hoynes et al., 2012; Coile et al., 2014; Bitler and Hoynes, 2015]). Regarding these widespread effects, John C. Williams (2011, p. 4), President and CEO of the Federal Reserve Bank of San Francisco, noted: “The main reason we care so much about financial stability is because financial crises can have devastating consequences for standard macroeconomic variables, such as employment, output, and inflation.” The devastating effects of financial crises may be avoided by neuroeconomics research that improves our understanding of currently anomalous asset-price bubbles.

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