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

John L. Haracz*
Goldman School of Public Policy, UC Berkeley and
Department of Psychological and Brain Sciences, Indiana University
jharacz@berkeley.edu

and

Daniel J. Acland
Goldman School of Public Policy, UC Berkeley
acland@berkeley.edu

Goldman School of Public Policy Working Paper

January 16, 2015

Abstract

Asset-price bubbles challenge the explanatory and predictive power of standard economic theory, suggesting that neuroeconomic measures should be explored as potential tools for improving 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.

*Corresponding author: John L. Haracz, Goldman School of Public Policy, UC Berkeley, 2607 Hearst Ave., Berkeley, CA 94720; phone: (510) 910-2025; email: jharacz@berkeley.edu

Acknowledgments

The authors appreciate comments by seminar participants at Stanford University and Chapman University. Portions of this material were presented at the 2013 and 2014 conferences of the Society for Neuroscience and the Society for Neuroeconomics.

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'Creevy 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; Hoynes et al., 2012; Bitler and Hoynes, 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, 2015]), thereby possibly curtailing the adverse health and socio-economic effects of prolonged recessions (Hoynes et al., 2012; Coile et al., 2014; Bitler and Hoynes, 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.
>
> Robert J. Shiller (2014, p. 1507)

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 [Alti 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.

VIII. References

Akerlof GA and Shiller RJ, *Animal Spirits: How Human Psychology Drives the Economy, and Why It Matters for Global Capitalism*. Princeton, NJ: Princeton University Press, 2009.

Alti A and Tetlock PC. Biased beliefs, asset prices, and investment: A structural approach. J. Finance 69:325-361, 2014.

Authers J. *The Fearful Rise of Markets: Global Bubbles, Synchronized Meltdowns, and How to Prevent Them in the Future*. Upper Saddle River, NJ: FT Press, 2010.

Baddeley M. Herding, social influence and economic decision-making: Socio-psychological and neuroscientific analyses. Phil. Trans. R. Soc. B 365:281-290, 2010.

Bajaj S, Drake D, Butler AJ, and Dhamala M. Oscillatory motor network activity during rest and movement: An fNIRS study. Frontiers in Systems Neuroscience 8:13, 2014.

Balke NS and Wohar ME. Market fundamentals versus rational bubbles in stock prices: A Bayesian perspective. J. Applied Econometrics 24:35-75, 2009.

Barber BM and Odean T. The behavior of individual investors. In: *Handbook of the Economics of Finance*, Vol. 2, Part B. Constantinides GM, Harris M, and Stulz RM, eds. Amsterdam: Elsevier, 2013, pp. 1533-1570.

Bernanke BS. The effects of the Great Recession on central bank doctrine and practice. B.E. Journal of Macroeconomics 12(3): Article 21, 2012.

Bernheim BD. On the potential of neuroeconomics: A critical (but hopeful) appraisal. American Economic Journal: Microeconomics 1(2):1-41, 2009.

Bernheim BD and Rangel A. Choice-theoretic foundations for behavioral welfare economics. In: *The Foundations of Positive and Normative Economics: A Handbook*. Caplin A and Schotter A, eds. NY: Oxford University Press, 2008, pp. 155-192.

Bien N and Sack AT. Dissecting hemisphere-specific contributions to visual spatial imagery using parametric brain mapping. NeuroImage 94:231-238, 2014.

Bijleveld E, Custers R, and Aarts H. Human reward pursuit: From rudimentary to higher-level functions. Current Directions in Psychological Science 21:194-199, 2012.

Bird A. *The Structure of Scientific Revolutions* and its significance: An essay review of the fiftieth anniversary edition. British Journal for the Philosophy of Science 63:859-883, 2012.

Bitler M and Hoynes H. Heterogeneity in the impact of economic cycles and the Great Recession: Effects within and across the income distribution. Goldman School of Public Policy, UC Berkeley Working Paper, January 12, 2015.

Bornstein AM and Daw ND. Cortical and hippocampal correlates of deliberation during model-based decisions for rewards in humans. PLoS Computational Biology 9(12):e1003387, 2013.

Brock WA and Hommes CH. A rational route to randomness. Econometrica 65:1059-1095, 1997.

Bruguier AJ, Quartz SR, and Bossaerts P. Exploring the nature of "trader intuition". J. Finance 65:1703-1723, 2010.

Burke CJ, Tobler PN, Schultz W, and Baddeley M. Striatal BOLD response reflects the impact of herd information on financial decisions. Frontiers in Human Neuroscience 4:48, 2010.

Bursztyn L, Ederer F, Ferman B, and Yuchtman N. Understanding mechanisms underlying peer effects: Evidence from a field experiment on financial decisions. Econometrica 82:1273-1301, 2014.

Camerer CF. Goals, methods, and progress in neuroeconomics. Annual Review of Economics 5:425-455, 2013.

Camerer CF, Loewenstein G, and Prelec D. Neuroeconomics: Why economics needs brains. Scandinavian J. Economics 106:555-579, 2004.

Caplin A and Dean M. The neuroeconomic theory of learning. American Economic Review 97(2):148-152, 2007.

Chang S-K. Herd behavior, bubbles and social interactions in financial markets. Studies in Nonlinear Dynamics & Econometrics 18:89-101, 2014.

Chiarella C and Di Guilmi C. The fiscal cost of financial instability. Studies in Nonlinear Dynamics & Econometrics 16(4): Article 3, 2012.

Cohen JD. The vulcanization of the human brain: A neural perspective on interactions between cognition and emotion. J. Economic Perspectives 19(4):3-24, 2005.

Cohn A, Engelmann J, Fehr E, and Maréchal M. Evidence for countercyclical risk aversion: An experiment with financial professionals. UBS Center Working Paper Series, Working Paper No. 4, August, 2013.

Coile CC, Levine PB, and McKnight R. Recessions, older workers, and longevity: How long are recessions good for your health? American Economic Journal: Economic Policy 6(3):92-119, 2014.

Colander D, Goldberg M, Haas A, Juselius K, Kirman A, Lux T, and Sloth B. The financial crisis and the systemic failure of the economics profession. Critical Review 21:249-267, 2009.

Coricelli G and Nagel R. Neural correlates of depth of strategic reasoning in medial prefrontal cortex. Proc. Natl. Acad. Sci. USA 106:9163-9168, 2009.

Cui X, Bray S, Bryant DM, Glover GH, and Reiss AL. A quantitative comparison of NIRS and fMRI across multiple cognitive tasks. NeuroImage 54:2808-2821, 2011.

Cutler DM, Poterba JM, and Summers LH. Speculative dynamics and the role of feedback traders. American Economic Review 80(2):63-68, 1990.

De Bondt W. Asset bubbles: Insights from behavioral finance. In: *New Perspectives on Asset Price Bubbles: Theory, Evidence, and Policy*. Evanoff DD, Kaufman GG, and Malliaris AG, eds. NY: Oxford University Press, 2012, pp. 318-332.

De Long JB, Shleifer A, Summers LH, and Waldmann RJ. Noise trader risk in financial markets. J. Political Economy 98:703-738, 1990.

De Martino B, O'Doherty JP, Ray D, Bossaerts P, and Camerer C. In the mind of the market: Theory of mind biases value computation during financial bubbles. Neuron 79:1222-1231, 2013.

Dixon ML and Christoff K. The lateral prefrontal cortex and complex value-based learning and decision making. Neuroscience and Biobehavioral Reviews 45:9-18, 2014.

Doty MM, Collins SR, Robertson R, and Garber T. Realizing health reform's potential – When unemployed means uninsured: The toll of job loss on health coverage, and how the Affordable Care Act will help. August, 2011. Available at: http://www.commonwealthfund.org/publications/issue-briefs/2011/aug/when-unemployed-means-uninsured, accessed October 25, 2014.

Edelson M, Sharot T, Dolan RJ, and Dudai Y. Following the crowd: Brain substrates of long-term memory conformity. Science 333:108-111, 2011.

Etkin A, Egner T, and Kalisch R. Emotional processing in anterior cingulate and medial prefrontal cortex. Trends in Cognitive Sciences 15(2):85-93, 2011.

Evanoff DD, Kaufman GG, and Malliaris AG. New perspectives on asset price bubbles: An overview. In: *New Perspectives on Asset Price Bubbles: Theory, Evidence, and Policy*. Evanoff DD, Kaufman GG, and Malliaris AG, eds. NY: Oxford University Press, 2012, pp. 3-10.

Evans CL. The international financial crisis: Asset price exuberance and macroprudential regulation. In: *The International Financial Crisis: Have the Rules of Finance Changed?* Demirgüç-Kunt A, Evanoff DD, and Kaufman GG, eds. Singapore: World Scientific, 2011, pp. 3-71.

Fan J, Van Dam NT, Gu X, Liu X, Wang H, Tang CY, and Hof PR. Quantitative characterization of functional anatomical contributions to cognitive control under uncertainty. J. Cognitive Neuroscience 26:1490-1506, 2014.

Fenton-O'Creevy M, Nicholson N, Soane E, and Willman P. *Traders: Risks, Decisions, and Management in Financial Markets*. Oxford: Oxford University Press, 2005.

Freeman J, Vladimirov N, Kawashima T, Mu Y, Sofroniew NJ, Bennett DV, Rosen J, Yang C-T, Looger LL, and Ahrens MB. Mapping brain activity at scale with cluster computing. Nature Methods 11:941-950, 2014.

Friedman BM. Struggling to escape from "Assumption 14". In: *New Perspectives on Asset Price Bubbles: Theory, Evidence, and Policy*. Evanoff DD, Kaufman GG, and Malliaris AG, eds. NY: Oxford University Press, 2012, pp. 341-350.

Frydman C, Barberis N, Camerer C, Bossaerts P, and Rangel A. Using neural data to test a theory of investor behavior: An application to realization utility. J. Finance 69:907-946, 2014.

Fuentes J, Poncela P, and Rodríguez J. Sparse partial least squares in time series for macroeconomic forecasting. J. Applied Econometrics, in press, doi: 10.1002/jae.2384.

Genovesio A, Wise SP, and Passingham RE. Prefrontal-parietal function: From foraging to foresight. Trends in Cognitive Sciences 18:72-81, 2014.

Glimcher PW and Fehr E, eds. *Neuroeconomics: Decision Making and the Brain*, 2nd Ed. Amsterdam: Elsevier, 2014.

Glimcher PW, Kable J, and Louie K. Neuroeconomic studies of impulsivity: Now or just as soon as possible? American Economic Review 97(2):142-147, 2007.

Greenspan A. *The Age of Turbulence: Adventures in a New World*. NY: Penguin, 2008.

Greer SM, Trujillo AJ, Glover GH, and Knutson B. Control of nucleus accumbens activity with neurofeedback. NeuroImage 96:237-244, 2014.

Griffin JM, Harris JH, Shu T, and Topaloglu S. Who drove and burst the tech bubble? J. Finance 66:1251-1290, 2011.

Gurkaynak RS. Econometric tests of asset price bubbles: Taking stock. J. Economic Surveys 22:166-186, 2008.

Haracz JL. Neuroeconomics of asset-price bubbles: A potential role for herding. 11th Annual Meeting, Society for Neuroeconomics, Lausanne, Switzerland, 2013.

Haracz JL and Acland DJ. Neuroeconomics and revealed-preference theory as synergistic cornerstones in economics: Linking neural and choice data may enable a novel self-regulatory policy for preventing asset-price bubbles. 12th Annual Meeting, Society for Neuroeconomics, Miami, Florida, 2014.

Hartwright CE, Apperly IA, and Hansen PC. Representation, control, or reasoning? Distinct functions for theory of mind within the medial prefrontal cortex. J. Cognitive Neuroscience 26:683-698, 2014.

Herwartz H and Kholodilin KA. In-sample and out-of-sample prediction of stock market bubbles: Cross-sectional evidence. J. Forecasting 33:15-31, 2014.

Hofmann MJ, Dambacher M, Jacobs AM, Kliegl R, Radach R, Kuchinke L, Plichta MM, Fallgatter AJ, and Herrmann MJ. Occipital and orbitofrontal hemodynamics during naturally paced reading: An fNIRS study. NeuroImage 94:193-202, 2014.

Holper L, Wolf M, and Tobler PN. Comparison of functional near-infrared spectroscopy and electrodermal activity in assessing objective versus subjective risk during risky financial decisions. NeuroImage 84:833-842, 2014.

Hoynes H, Miller DL, and Schaller J. Who suffers during recessions? J. Economic Perspectives 26(3):27-48, 2012.

Kedia G, Mussweiler T, Mullins P, and Linden DEJ. The neural correlates of beauty comparison. Social Cognitive and Affective Neuroscience 9:681-688, 2014.

Klucharev V, Hytönen K, Rijpkema M, Smidts A, and Fernández G. Reinforcement learning signal predicts social conformity. Neuron 61:140-151, 2009.

Knutson B and Bossaerts P. Neural antecedents of financial decisions. J. Neuroscience 27:8174-8177, 2007.

Kober SE, Wood G, Kurzmann J, Friedrich EVC, Stangl M, Wippel T, Väljamäe A, and Neuper C. Near-infrared spectroscopy based neurofeedback training increases specific motor imagery related cortical activation compared to sham feedback. Biological Psychology 95:21-30, 2014.

Kopton IM and Kenning P. Near-infrared spectroscopy (NIRS) as a new tool for neuroeconomic research. Frontiers in Human Neuroscience 8:549, 2014.

Laureiro-Martínez D, Canessa N, Brusoni S, Zollo M, Hare T, Alemanno F, and Cappa SF. Frontopolar cortex and decision-making efficiency: Comparing brain activity of experts with different professional background during an exploration-exploitation task. Frontiers in Human Neuroscience 7:927, 2014.

Lewis M. *Flash Boys: A Wall Street Revolt.* NY: Norton, 2014.

Lim K-P and Brooks R. The evolution of stock market efficiency over time: A survey of the empirical literature. J. Economic Surveys 25:69-108, 2011.

Lohrenz T, McCabe K, Camerer CF, and Montague PR. Neural signature of fictive learning signals in a sequential investment task. Proc. Natl. Acad. Sci. USA 104:9493-9498, 2007.

Louca F. The demise of critical theory in economics. In: *Cognitive Justice in a Global World: Prudent Knowledges for a Decent Life*. Santos BdS, ed. Lanham, MD: Lexington, 2007, pp. 315-336.

Lux T. Herd behaviour, bubbles and crashes. Economic Journal 105:881-896, 1995.

Mackey AP, Miller Singley AT, and Bunge SA. Intensive reasoning training alters patterns of brain connectivity at rest. J. Neuroscience 33:4796-4803, 2013.

Madrian BC. Applying insights from behavioral economics to policy design. Annual Review of Economics 6:663-688, 2014.

Morgan TJH and Laland KN. The biological bases of conformity. Frontiers in Neuroscience 6:87, 2012.

Ogawa A, Onozaki T, Mizuno T, Asamizuya T, Ueno K, Cheng K, and Iriki A. Neural basis of economic bubble behavior. Neuroscience 265:37-47, 2014.

Palan S. A review of bubbles and crashes in experimental asset markets. J. Economic Surveys 27:570-588, 2013.

Palley TI. Monetary policy at the zero lower bound and after: A reassessment of quantitative easing and critique of the Federal Reserve's proposed exit strategy. Metroeconomica 66:1-27, 2015.

Piper SK, Krueger A, Koch SP, Mehnert J, Habermehl C, Steinbrink J, Obrig H, and Schmitz CH. A wearable multi-channel fNIRS system for brain imaging in freely moving subjects. NeuroImage 85:64-71, 2014.

Plassmann H, O'Doherty J, and Rangel A. Orbitofrontal cortex encodes willingness to pay in everyday economic transactions. J. Neuroscience 27:9984-9988, 2007.

Poldrack RA, Barch DM, Mitchell JP, Wager TD, Wagner AD, Devlin JT, Cumba C, Koyejo O, and Milham MP. Toward open sharing of task-based fMRI data: The OpenfMRI project. Frontiers in Neuroinformatics 7:12, 2013.

Poline J-B, Breeze JL, Ghosh S, Gorgolewski K, Halchenko YO, Hanke M, Haselgrove C, Helmer KG, Keator DB, Marcus DS, Poldrack RA, Schwartz Y, Ashburner J, and Kennedy DN. Data sharing in neuroimaging research. Frontiers in Neuroinformatics 6:9, 2012.

Prado J, Chadha A, and Booth JR. The brain network for deductive reasoning: A quantitative meta-analysis of 28 neuroimaging studies. J. Cognitive Neuroscience 23:3483-3497, 2011.

Raafat RM, Chater N, and Frith C. Herding in humans. Trends in Cognitive Sciences 13:420-428, 2009.

Reinhart CM and Rogoff KS. *This Time Is Different: Eight Centuries of Financial Folly*. Princeton, NJ: Princeton University Press, 2009.

Reyna VF. A new intuitionism: Meaning, memory, and development in Fuzzy-Trace Theory. Judgment and Decision Making 7:332-359, 2012.

Reyna VF and Huettel SA. Reward, representation, and impulsivity: A theoretical framework for the neuroscience of risky decision making. In: *The Neuroscience of Risky Decision Making*. Reyna VF and Zayas V, eds. Washington, DC: American Psychological Association, 2014, pp. 11-42.

Robineau F, Rieger SW, Mermoud C, Pichon S, Koush Y, Van De Ville D, Vuilleumier P, and Scharnowski F. Self-regulation of inter-hemispheric visual cortex balance through real-time fMRI neurofeedback training. NeuroImage 100:1-14, 2014.

Roubini N. Why central banks should burst bubbles. International Finance 9(1):87-107, 2006.

Rudorf S, Kuhnen CM, and Weber B. Risk learning signals predict optimal investment choices. 12th Annual Meeting, Society for Neuroeconomics, Miami, Florida, 2014.

Scharfstein DS and Stein JC. Herd behavior and investment. American Economic Review 80:465-479, 1990.

Scholkmann F, Kleiser S, Metz AJ, Zimmermann R, Pavia JM, Wolf U, and Wolf M. A review on continuous wave functional near-infrared spectroscopy and imaging instrumentation and methodology. NeuroImage 85:6-27, 2014.

Shiller RJ. *Finance and the Good Society*. Princeton, NJ: Princeton University Press, 2012.

Shiller RJ. Speculative asset prices. American Economic Review 104:1486-1517, 2014.

Shimokawa T, Suzuki K, Misawa T, and Miyagawa K. Predictability of investment behavior from brain information measured by functional near-infrared spectroscopy: A Bayesian neural network model. Neuroscience 161:347-358, 2009.

Shirer WR, Ryali S, Rykhlevskaia E, Menon V, and Greicius MD. Decoding subject-driven cognitive states with whole-brain connectivity patterns. Cerebral Cortex 22:158-165, 2012.

Smith A, Lohrenz T, King J, Montague PR, and Camerer CF. Irrational exuberance and neural crash warning signals during endogenous experimental market bubbles. Proc. Natl. Acad. Sci. USA 111:10503-10508, 2014.

Smith VL, Suchanek GL, and Williams AW. Bubbles, crashes, and endogenous expectations in experimental spot asset markets. Econometrica 56:1119-1151, 1988.

Stein JC. Overheating in credit markets: Origins, measurement, and policy responses. Remarks at "Restoring Household Financial Stability after the Great Recession: Why Household Balance Sheets

Matter”, a Research Symposium sponsored by the Federal Reserve Bank of St. Louis, February 7, 2013. Available at: http://www.federalreserve.gov/newsevents/speech/stein20130207a.htm, accessed February 10, 2013.

Stein JC. Incorporating financial stability considerations into a monetary policy framework. Remarks at the International Research Forum on Monetary Policy, which was sponsored by the European Central Bank, the Federal Reserve Board, the Center for Financial Studies at the Goethe University, and the Georgetown Center for Economic Research at Georgetown University, March 21, 2014. Available at: http://www.federalreserve.gov/newsevents/speech/stein20140321a.htm, accessed October 25, 2014.

Stiglitz JE. Rethinking macroeconomics: What failed, and how to repair it. J. European Economic Association 9:591-645, 2011.

Stiglitz JE. *The Price of Inequality: How Today's Divided Society Endangers Our Future*. NY: Norton, 2012.

Stiglitz JE. The lessons of the North Atlantic crisis for economic theory and policy. In: *What Have We Learned? Macroeconomic Policy after the Crisis.* Akerlof G, Blanchard O, Romer D, and Stiglitz J, eds. Cambridge, MA: MIT Press, 2014, pp. 335-347.

Vogel HL. *Financial Market Bubbles and Crashes.* NY: Cambridge University Press, 2010.

Wendelken C, Chung D, and Bunge SA. Rostrolateral prefrontal cortex: Domain-general or domain-sensitive? Human Brain Mapping 33:1952-1963, 2012.

Williams JC. Monetary policy in an era of crises. Remarks at the International Monetary Fund Annual Research Conference, Washington, DC, November 11, 2011.

Yellen JL. Closing panel presentation. J. Money, Credit and Banking 42:243-248, 2010.

Zaki J, Schirmer J, and Mitchell JP. Social influence modulates the neural computation of value. Psychological Science 22:894-900, 2011.

Zhu L, Walsh D, and Hsu M. Neuroeconomic measures of social decision-making across the lifespan. Proc. Natl. Acad. Sci. USA 109:1419-1424, 2012.