



# Evaluating the emotional bidding framework: new evidence from a decade of neurophysiology

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## Abstract

Ten years ago the “emotional bidding framework” (Adam et al., *Electronic Markets*, 21(3), 197–207, 2011b) was published in this journal. It provided a conceptualization for the role of human emotion in electronic auctions along six propositions on how emotions emerge during the auction process and affect auction outcomes. While the framework emphasized the importance of immediate emotional responses and momentary changes in the bidders’ emotional state, the original article did not include an evaluation of its propositions given the limited data on how bidders experience emotions in the moment that they occur. Ten years on, advances in the growing research field of NeuroIS allow to evaluate the propositions based on neurophysiological evidence. As a rejoinder of the original article, the present paper synthesizes these insights, refines the framework further, and identifies fruitful areas for future research based on remaining gaps in the body of knowledge.

**Keywords** Auctions · Auction Fever · NeuroIS

**JEL classification** D44 · L81

## Introduction

Electronic auctions (i.e., electronic auction marketplaces) are information systems (IS) that facilitate and structure the exchange of products and services between potential buyers and sellers. In practice, electronic auctions have been employed for a wide range of goods and services, such as commodities (e.g., Internet consumer auction markets, such as [eBay.com](https://www.eBay.com)), perishable goods (e.g., Dutch flower markets, such as by Royal FloraHolland), consumer services (e.g., procurement auction markets, such as [myhammer.com](https://www.myhammer.com)), or stocks (e.g., financial double auction

markets such as NASDAQ). In this vein, electronic auctions facilitate a large share of our private and commercial economic activity today (Ku et al., 2005; Lu et al., 2019).

A decade ago, Adam et al. (2011b) proposed an emotional bidding framework in this journal, which captures how the design of electronic auctions can affect the bidders’ emotional state and thereby auction outcomes. At the time, scholars became increasingly cognizant of the role of bidders’ emotions, such as the “joy of winning” or the “fear of losing” (Delgado et al., 2008) in the auction process, which are believed to culminate in a state of “competitive arousal” that is elicited during auction participation (Ku et al., 2005). Drawing from previous research in information systems, economics, and psychology, the emotional bidding framework posited six propositions on the links between the auction design as well as the auction process on the bidders’ emotions, which, at the time, still needed to be validated empirically. More specifically, when the emotional bidding framework was devised, it could already draw from a large body of literature on auction theory (e.g., McAfee & McMillan, 1987; Parsons et al., 2011) and empirical studies on bidding behavior (e.g., Ku et al., 2005; Murnighan, 2002), but neurophysiological evidence (e.g., brain imaging, heart rate, skin conductance) for the proposed links between bidding behavior and a bidder’s emotional processes was still scant.

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An important development since the publication of the emotional bidding framework is the increasing body of IS research that uses neurophysiological methods to investigate emotions in human-computer interaction. This subfield of the IS field is also known as NeuroIS (Riedl et al., 2010). Since its inception in December 2007, NeuroIS has developed considerable momentum over the past decade (Riedl et al., 2020). Specifically, NeuroIS enables researchers to draw new insights “which cannot be gained otherwise” (vom Brocke et al., 2020, p. 11). For the understanding of emotion in human-computer interaction particular, neurophysiological methods enable researchers to measure correlates of human emotion in situ, that is, in the very moment users of IS experience them. The propositions in the emotional bidding framework directly pertain to bidders emotional processing during auctions, and thus the new insights provided by NeuroIS studies are an invaluable resource for assessing the validity of the emotional bidding framework’s propositions.

As a rejoinder of the original article, the present paper sets out to build on the advances in the NeuroIS field to revisit the emotional bidding framework and evaluate its propositions with the neurophysiological evidence that has emerged on human emotional processing in auctions.<sup>1</sup> Overall, it can be concluded that the neurophysiological studies confirm the propositions of the original emotional bidding framework. However, our synthesis also reveals that some of the propositions are difficult to disentangle by means of neurophysiological measurements, and that some research gaps remain. Based on our insights, we refine the emotional bidding framework, and point at open research questions and avenues for future research on understanding the role of emotions in electronic auctions.

## Theoretical background

### Affective processing and emotions in electronic markets

Emotions play an important role for how users perceive and experience electronic markets. The design of electronic markets (e.g., which information is relayed when and to whom) can trigger affective processes in the user, which through the vehicle of emotion shape users’ attitudes, beliefs, and response tendencies. With and without conscious awareness, these processes ultimately influence user behavior. As famously stated by Bradley (2007, p. 602), “it sometimes seems that there are as many definitions [of emotion] as there are investigators.” Reflecting a rather general understanding of emotions in psychological literature, the term emotion can be roughly defined as a subjectively experienced state that can be described qualitatively and is accompanied by changes in feeling, physiology, and expression (Myers, 2004). Thus, a subjectively experienced feeling is only a part of the broader concept of emotion, which also comprises objectively observable changes, e.g., in neurophysiology.

In the present work, we build on Rick and Loewenstein (2008)’s conceptualization and distinguish between a person’s (1) immediate emotions and (2) their overall emotional state. Taking a consequentialist perspective, Rick and Loewenstein (2008) were interested in the different types of emotions linked to the consequences of one’s economic decision making. Within this conceptualization, an *immediate emotion* refers to a short burst of emotional experience which is elicited by an internal (e.g., fear in response to thinking about an unpleasant event) and/or external stimulation (e.g., joy in response to learning about a discount). By contrast, the *emotional state* refers to a person’s overall state of emotion and, thereby, canalizes the influence of emotional reactions. Importantly, while immediate emotions are transient, the emotional state is ongoing and “the individual is never *without* being in some emotional state” (Zajonc, 1984, p. 21). Thereby, it is important to differentiate immediate emotions from *expected emotions*. Expected emotions are anticipated to occur at a later point in time (e.g., as the result of winning or losing an auction when the outcome materializes), but – in contrast to immediate emotions – expected emotions are not experienced immediately (Rick & Loewenstein, 2008). Yet, expected emotions can eventually trigger an immediate emotion by functioning

<sup>1</sup> The idea for the present article was sparked by a book chapter invitation for a celebratory edited volume on the advances in the research field of market engineering over the past decades (Adam & Krämer, 2021). Reflecting on this book chapter, the authors significantly extended their original work by developing a revised version of the emotional bidding framework, elaborating on the contributions and specific insights of individual neurophysiological measurements, and identifying knowledge gaps and opportunities for future research. We thank two anonymous referees and the editors for very valuable comments.

as an internal simulation regarding a future event (e.g., an immediate fear of losing).

Given the focus of this article on neurophysiological evidence, two observations are particularly noteworthy in this context. First, at this stage neurophysiological measurements can only measure correlates of changes in immediate emotions and the overall emotional state, but not expected emotions. Second, given that immediate emotions can be triggered by an internal and/or external stimulation, it can be challenging to determine the trigger of an immediate emotion with some confidence. Specifically, immediate emotions may be triggered directly by an (internal or external) stimulus, or indirectly through an expected emotion. We will return to these pathways in Section 3.2, when mapping the neurophysiological evidence to the propositions of the framework.

Finally, it is important to note that according to Russell (1980)'s circumplex model, emotions in general can be roughly differentiated in an *arousal* dimension (i.e., the strength of an emotion) and a *valence* dimension (i.e., the pleasantness of an emotion). For example, while the joy of winning is a pleasant emotion (ranks high in the valence dimension), the frustration of losing is an unpleasant emotion (ranks low in the valence dimension), albeit both types of emotion may exhibit similar arousal levels.

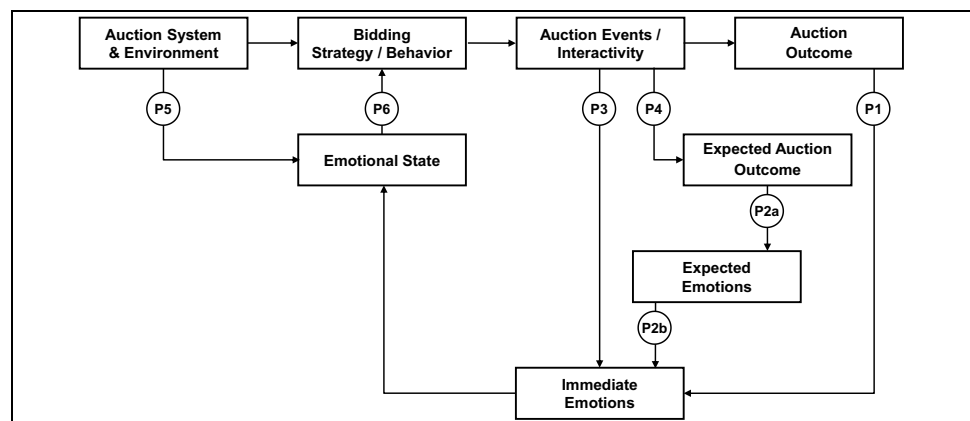
## Emotional bidding framework

In order to conceptualize the role of human emotion in auction bidding, Adam et al. (2011b) introduced an integrative theoretical framework that captures the emergence and impact of emotions in electronic auctions (see Fig. 1). This emotional bidding framework considers Rick and Loewenstein (2008) previously mentioned distinction between (short-lived) immediate emotions and a person's (ongoing) overall emotional state, as well as expected emotions as an integral trigger for immediate emotions. Moreover, the framework builds on the competitive arousal model by Ku et al. (2005) that posits that certain features of competitive

contexts (e.g., time pressure, perceived rivalry) can increase arousal (which, as introduced above, is an important dimension of an emotion). Heightened arousal levels may then increase bidders' desire to win at all costs, even if this is difficult to justify from a purely economic perspective. Since its emergence in 2005, the competitive arousal model has stimulated considerable research and remains a popular conceptualization of emotions' role in competitive contexts (Ku & Adam, 2022).

The top row of the emotional bidding framework (Auction System & Environment → Auction Outcome) reflects the traditional, economic perspective of auction theory on cause-and-effect relationships that ultimately determine auction outcomes (McAfee & McMillan, 1987). Assuming an emotionless homo economicus, who is fully rational and has the ability to assess all available information and possible strategic interactions, the (equilibrium) bidding strategy is determined ex-ante and depends only on the auction system and environment (i.e., the set of rules governing the auction, the number of competitors, etc.). From a purely game-theoretic point of view, there is no need to modify the bidding strategy during the auction, as a "strategy" in the game-theoretic sense is defined as a complete action plan, considering all contingencies on and off the equilibrium path. Hence, under the traditional economic view, the cause-and-effect relationship between the auction system and environment and the auction outcome is unidirectional and does not contain feedback loops (Adam et al., 2011b). Clearly, the top row is an abstraction of the theoretical complexities that can arise in the various auction formats, including, e.g., the possibility for Bayesian updating as the bidding process unfolds. In the context of the emotional bidding framework it mainly serves the purpose to denote possible triggers of emotions before and during the auction process, as well as the feedback loop that a bidder's emotional state can have on their bidding behavior.

**Fig. 1** Emotional Bidding Framework (adapted from Adam et al., 2011b)



The focus of the emotional bidding framework lies in the bottom row, where the framework takes into account the emergence and impact of affective processes on human bidding behavior and auction outcomes. In this vein, the emotional bidding framework explicitly takes into account psychological feedback loops that are not considered in the traditional economic perspective. In other words, the assumption of a *homo economicus* is thereby complemented by the assumption of a *homo emoticus* (Sigmund et al., 2002). The specific cause-and-effect relationships between a bidder's emotional state (i.e., their overall arousal and valence of affective processing) and their immediate emotions (e.g., joy of winning, frustration of losing) is made explicit by a set of theoretical propositions as listed in Table 1.

### Neurophysiological measurements

The field of NeuroIS draws upon the theories, methods, and tools in neurophysiology to advance the design, evaluation, and understanding of information systems (Riedl et al., 2014). This includes techniques for measuring brain activation such as functional magnetic resonance imaging (fMRI), electroencephalography (EEG), and positron emission tomography (PET) as well as other neurophysiological measurements such as heart rate (HR), pupil dilation (PD), and skin conductance

(SC) measurements. By linking these neurophysiological measurements to users' perceptions and behaviors, researchers can investigate the role of human affective processing in human-computer interaction (vom Brocke et al., 2020). In applying these measurements, researchers need to carefully consider the specific insights that a particular measurement technique can provide on a targeted psychological construct (e.g., arousal, cognitive load, stress) as well as its corresponding financial and environmental constraints (e.g., cost of measurement, applicability in field settings).

*Peripheral measurements* (HR, PD and SC) can be achieved with relatively low-cost and by wearable devices with high reliability, but cannot provide insight into the activation of specific brain regions. However, peripheral measures are generally able to capture the valence and arousal dimension of an emotion, which provides important insights into a bidder's overall emotional state (e.g., the level of competitive arousal during auction participation) and the emergence of specific immediate emotions (e.g., the intensity of the joy of winning and the frustration of losing). Some of these measures (e.g., HR, SC) have also found their way into day-to-day wearable technology, such as smartwatches or smartphones, which renders them attractive for in-situ field research. Table 2 provides a brief overview of the neurophysiological correlates that researchers have

**Table 1** Propositions in the emotional bidding framework

Proposition	Components in the framework
<b>P1:</b> <i>The auction outcome can directly induce immediate emotions.</i>	P1 refers to the emergence of a <i>direct</i> , immediate emotion (e.g., winner regret, loser regret) in response to learning the auction outcome.
<b>P2:</b> <i>The expected auction outcome may induce bidders to anticipate expected emotions (P2a), which may in turn induce immediate emotions (P2b).</i>	P2 captures that immediate emotions can also be triggered by thinking about a <i>future</i> auction outcome. For instance, during auction participation a bidder could be concerned about losing the auction in the future, triggering an immediate "fear of losing" while the auction is still running.
<b>P3:</b> <i>Auction events can directly induce immediate emotions.</i>	P3 captures immediate emotions that <i>directly</i> originate from auction events. For instance, a bidder may feel frustration when losing the high bidder status in response to a bid from a competitor.
<b>P4:</b> <i>Auction events can influence a bidder's perception about the expected auction outcome, and thus (via P2) indirectly induce immediate (anticipatory) emotions.</i>	P4 captures immediate emotions that <i>indirectly</i> originate from auction events (e.g., placing a bid, seeing someone else's bid). For instance, a bidder who loses the high bidder status may as a result get concerned about losing the auction, triggering an immediate "fear of losing". This can occur immediately in conjunction with a specific auction event, but it can also occur delayed or independently of such an external stimulus.
<b>P5:</b> The auction system & environment can directly influence a bidder's emotional state.	P5 refers to the general impact that the auction system & environment has on a bidder's emotional impact (e.g., the degree of time pressure, the presence of an audience).
<b>P6:</b> A bidder's current emotional state can influence bidding behavior.	P6 captures the notion that the emergence of emotions does not only affect a bidder's experience of their current emotional state, but can cause a change in their behavior (e.g., placing a higher bid).

**Table 2** Neurophysiological measures used for researching human emotion in auction bidding

Neurophysiological measure	Brief description	Auction bidding research
Functional Magnetic Resonance Imaging (fMRI)	Functional magnetic resonance imaging (fMRI) enables researchers to assess brain activity by quantifying the blood oxygen levels in different brain areas (Riedl et al., 2014; Riedl and Léger, 2016). This allows assessing the intensity of emotional experience in areas such as the anterior insulae and the striatum.	van den Bos et al. (2013), Delgado et al. (2008)
Heart Rate (HR)	Based on electrocardiogram (ECG) or photoplethysmogram (PPG) measurements, <sup>1</sup> HR captures both sympathetic and parasympathetic activity. It can be averaged across longer time periods to assess overall arousal, or changes in HR following discrete events can be used to assess immediate emotions. Further, the variability of successive heart beats can be used to assess HR variability metrics as proxies for sympathetic and parasympathetic activation. (Lang et al., 1993; Velden and Völk, 1987)	Adam (2010), Adam et al. (2011a), Adam et al. (2012, 2015, 2016, 2019), Astor et al. (2013a), Astor et al. (2011), Hariharan et al. (2016), Smith and Dickhaut (2005), Teubner et al. (2015)
Skin Conductance (SC)	Commonly measured at the palm, SC refers to the electrical conductivity of the human skin. It can be decomposed into a tonic (skin conductance level, SCL) and a phasic component (skin conductance response, SCR) of sympathetic activity. SCL is a measure for the current emotional state's overall arousal level, whereas SCR represents short bursts of sympathetic activity in the form of immediate emotions. (Boucsein, 2012; Dawson et al., 2011)	Adam (2010), Adam et al. (2011a), Adam et al. (2012, 2015, 2016), Astor et al. (2013a), Astor et al. (2011), Teubner et al. (2015)

used for investigating the role of emotions in auction bidding.<sup>2</sup>

## Results from neurophysiological studies

Since the establishment of the emotional bidding framework in 2011, a range of neurophysiological studies have investigated the emergence and impact of a bidder's immediate emotions and current emotional state. In the following, we provide an overview of how the results of these studies map to the framework's propositions. Table 3 provides a summary of this mapping.

### Immediate emotions in response to auction outcome (P1)

The revelation of the auction outcome is arguably the single most anticipated event in any auction. After all, the auction outcome brings clarity in terms of resource allocation (who gets what) and price determination (who pays what), which is commonly the primary purpose of conducting an auction in the first place. Providing support for P1, studies

using neurophysiological measurements have shown that the announcement of the auction outcome can trigger a range of immediate emotions with varying intensities.

While overall studies have shown that the emotions in response to winning an auction are stronger than those of losing an auction, both for sealed-bid (Astor et al., 2013a; Teubner et al., 2015; van den Bos et al., 2013) and ascending clock auctions (Adam et al., 2015), it is important to note that this is not the case for descending clock auctions. Specifically, Adam et al. (2012) found that in descending clock ("Dutch") auctions the skin conductance responses triggered by losing an auction are stronger than those in response to winning an auction. The authors explained this with the "click-to-win" characteristic of Dutch auctions, where losing comes as an unpleasant surprise. Further, pointing to the importance of the "social competition" (Delgado et al., 2008) inherent to auctions, immediate emotions in response to auction outcomes are higher when competing with human bidders than they are when competing with computerized bidders (Adam et al., 2015; Teubner et al., 2015).

A different perspective on winning and losing is to consider whether the bidder *could* have achieved a more favorable result if they had placed a slightly different bid. The immediate emotions associated with these *ex-post* considerations are referred to as winner regret and loser regret (Engelbrecht-Wiggans & Katok, 2008). Winner regret refers to the notion that the bidder could have still won the auction but achieved a higher profit by placing a slightly lower bid. By contrast, loser regret refers to the notion that the bidder lost

<sup>2</sup> The smoothness of the pulse wave complicates the exact detection of peaks in the PPG signal. Moreover, the time between the heart beat and the peak of the pulse wave (i.e., pulse transit time) changes with blood pressure (Obtist et al., 1979). Therefore, ECG-recordings are generally better suited to assess HR changes.

**Table 3** Mapping between the framework's propositions and results from neurophysiological studies

Proposition	Empirical results	Proposition confirmed?	
<b>P1:</b> <i>The auction outcome can directly induce immediate emotions.</i>	Losing a sealed-bid auction triggers stronger immediate emotions (brain activity in striatum) than losing an equivalent lottery removed from the auction context (Delgado et al., 2008)	Yes (stronger when losing a static auction)	
	Winning and losing can induce feelings of loser regret and winner relief in bidders (Astor et al., 2011)	Yes (stronger for loser regret)	
	Losing a descending clock auction induces stronger immediate emotions (skin conductance response) than winning it (Adam et al., 2012)	Yes (stronger when losing a dynamic, descending auction)	
	Winning a sealed-bid auction induces stronger immediate emotions (brain activity, skin conductance) than losing it (Astor et al., 2013a; Teubner et al., 2015; van den Bos et al., 2013)	Yes (stronger when winning a static auction)	
	Winning an ascending clock auction induces stronger immediate emotions (skin conductance response) than losing it (Adam et al., 2015)	Yes (stronger when winning a dynamic ascending auction)	
<b>P2:</b> <i>The expected auction outcome may induce bidders to anticipate expected emotions (P2a), which may in turn induce immediate emotions (P2b).</i>	Placing a bid under high time pressure induces weaker immediate emotions than placing a bid under low time pressure (Adam, 2010)	Yes (confirms effect of auction events on immediate emotions, but unclear whether via P3 or P2/P4)	
<b>P3:</b> <i>Auction events can directly induce immediate emotions.</i>	Submitting a sealed bid triggers skin conductance responses, the intensity of which is positively related to the amount of money at stake (Teubner et al., 2015)	Yes (confirms effect of auction events on immediate emotions, but unclear whether via P3 or P2/P4)	
<b>P4:</b> <i>Auction events can influence a bidder's perception about the expected auction outcome, and thus (via P2) indirectly induce immediate (anticipatory) emotions.</i>	Descending clock auctions induce higher arousal (heart rates) than ascending clock auctions (Smith & Dickhaut, 2005)	Yes (via auction type)	
	Bidders' arousal (heart rates, skin conductance) is positively linked to the amount of money at stake for the bidder (Adam, et al., 2011a; Teubner et al., 2015)	Yes (via amount of money at stake)	
	Faster clock speeds in ascending clock auctions are linked to higher arousal (heart rates) (Adam et al., 2015)	Yes (via time pressure)	
	Competing with human bidders induces higher arousal (heart rates) than competing with computerized agents (Adam et al., 2015; Teubner et al., 2015)	Yes (via bidder type [human or computer])	
	Descending clock auctions induce higher arousal (heart rates) than first-price sealed bid auctions (Hariharan et al., 2016)	Yes (via auction dynamics)	
	Affective imagery in the auction environment increases bidders' overall arousal (Adam et al., 2016, 2019)	Yes (via images)	
	<b>P6:</b> <i>A bidder's current emotional state can influence bidding behavior.</i>	Higher overall arousal (heart rates), elicited through time pressure, is linked to lower bids in descending clock auctions (Adam et al., 2012)	Yes (via arousal)
		Higher overall arousal (heart rates), elicited through time pressure, is linked to higher bids in ascending clock auctions (Adam et al., 2015)	Yes (via arousal)
Pleasant emotions (low valence), elicited through imagery, is linked to higher bids than unpleasant emotions (high valence) (Adam et al., 2016)		Yes (via valence)	
Higher arousal in sealed-bid auctions is linked to higher (lower) bids in common value (/private value) settings (Adam et al., 2019; Teubner et al., 2015)		Yes (direction depends on value model)	

the auction but could have won the auction with a profit by placing a slightly higher bid. Note that such regret can only occur in first-price auctions, where bidders have to pay what they bid. Based on skin conductance measurements, Astor et al. (2011) showed that both of these events induce immediate emotions and that, as predicted by Engelbrecht-Wiggans and Katok (2008), loser regret is experienced more strongly than winner regret. However, Astor et al. (2011) also showed that the intensity of immediate emotions *increases* the closer the bidder's successful bid was to the second highest bid. This finding is in conflict with the Engelbrecht-Wiggans and Katok (2008)'s assumptions underlying the concept of *winner regret* and instead is more congruent with an emotion of *winner relief* (Astor et al., 2011).

### Immediate emotions in response to auction events (P2-P4)

The emergence of immediate emotions during auction participation is arguably the most complex part of the cause-and-effect relationships captured in the emotional bidding framework. After all, immediate emotions could be linked (1) to spontaneous considerations in the bidder's mind that cannot be linked to an individual auction event (e.g., a sudden fear of losing the auction when thinking about the prospective auction outcome, P2), (2) to *direct* emotional responses to an auction event (e.g., frustration when losing the high bidder status, P3), or (3) to *indirect* emotional responses to an auction event (e.g., fear of losing the auction in response to losing high bidder status, P4/P2). Given this complex setting and the difficulty in linking neurophysiological responses to one or more of these theoretical pathways, only few neurophysiological studies have attempted to investigate the emergence of immediate emotions during auction participation.

The limited literature that exists on this matter supports the general notion that bidders experience immediate emotions during auction participation. Specifically, two studies have shown that bidders experience immediate emotions in response to individual auction events (cf. P3 and P4). Teubner et al. (2015) found in the context of sealed-bid auctions that submitting a bid and waiting for the result triggered immediate emotions as measured by bidders' skin conductance responses, the intensity of which increased with amounts of money at stake. Similarly, Adam (2010) found evidence for immediate emotions in response to placing a bid in ascending auctions. Thereby, the skin conductance responses elicited in high time pressure auctions were weaker than the responses elicited in low time pressure auctions. Although these studies confirm the emergence and the varying intensities of immediate emotions at specific auction events, it is important to note that these studies were not able to clarify whether these immediate emotions were

a *direct* response to the auction event (e.g., joy of placing a bid, P3) or an *indirect* response pertaining to expectations about future events (e.g., fear of losing, P4). In other words, the extant studies cannot disentangle the pathway through which the immediate emotion is triggered, i.e., whether it is triggered directly by the auction event via P3, or whether it is triggered indirectly by inducing an expected emotion via P4/P2. It is also unclear whether neurophysiological measures alone can ever achieve this aim, because ultimately only correlates of immediate emotions can be measured. In order to clarify the pathway, one would need to know if and what bidders were thinking about expected auction outcomes *before* they experience the emotion. We will return to this challenge in our prospects for future research. Nevertheless, for a conceptual framework it is important to acknowledge that different pathways for triggering immediate emotions may exist, albeit to date there exists, to the best of our knowledge, no study that disentangles the two pathways.

### Impact of the auction system and environment on a bidder's emotional state (P5)

The auction system and environment includes a multiplicity of factors that may affect a bidder's emotional state. Conceptually, we can distinguish (1) *integral* factors that directly pertain to the auction context (e.g., the time between price steps set by the auctioneer) and (2) *incidental* factors that are outside the auction context (e.g., visual stimuli such as imagery unrelated to the auction). As noted by Adam et al. (2019), incidental factors could even extend to aspects in the bidders' wider socio-economic environment that are seemingly irrelevant to the auction such as a visit to the gym, a strong espresso, a heated argument, or listening to upbeat music right before attending the auction. Providing support for P5, several neurophysiological studies found evidence for an influence of both integral and incidental factors on a bidder's emotional state.

In terms of *integral* factors, one stream of literature has considered the speed of price changes in ascending and descending clock auctions. Specifically, it was shown that when increasing the clock speed from five seconds per price change to 0.5 seconds per price change, bidders showed higher heart rates (Adam et al., 2012, 2015). Further, bidders' arousal levels are positively linked to the amount of money at stake in the auction (Adam et al., 2011a; Teubner et al., 2015). Finally, research showed that competing with other human bidders instead of computerized bidders is another important driver for arousal in auctions (Adam et al., 2015; Teubner et al., 2015). In terms of *incidental* factors, research has shown that seemingly unrelated imagery in the auction environment affect a bidders' current emotional state. For instance, Adam et al. (2016) showed that competitive images (e.g., pictures of competitive sports) created a

different emotional state in bidders than community images (e.g., pictures of family scenes).

### Impact of a bidder's emotional state on their bidding behavior (P6)

Researchers in psychology have long conjectured that factors in the auction system and environment may not only change a bidder's emotional state but that this change in the emotional state may also affect their bidding behavior (Ku et al., 2005; Murnighan, 2002). In the literature, this impact of the emotional state on bidding behavior is often referred to as auction fever. Referring to the visceral nature of auction fever, Murnighan (2002, p. 63) conjectured that during auction fever bidders' "adrenaline starts to rush, their emotions block their ability to think clearly, and they end up bidding more than they ever envisioned." Providing support for P6, studies using neurophysiological measurements have linked changes in a bidder's emotional state to their bidding behavior.

Here, we may again differentiate whether the heightened emotional state was elicited by integral factors, such as time pressure, or by incidental factors, such as seemingly unrelated imagery. Focusing on the role of time pressure (clock speeds) in clock auctions – which is an integral factor – Adam et al. (2012) and Adam et al. (2015) showed that the way in which the emotional state affects bidding behavior depends on the auction mechanism. While in ascending auctions higher arousal is associated with higher bids, the reverse is true for descending auctions, where higher arousal is linked to lower bids (Adam et al., 2012).

Next to differences in the bidders' emotional state with respect to arousal, NeuroIS research also confirmed that differences in bidders' emotional state with respect to valence (being the other dimension) can influence bidding behavior. Adam et al. (2016) used seemingly unrelated imagery – which is an incidental factor – presented before the auction to induce differences in valence levels of the bidders' emotional state, while keeping bidder's arousal level constant. They then showed that pleasant emotions (low valence) led to higher bids than unpleasant emotions (high valence).

Further research showed that the link between a bidder's emotional state and their bidding behavior does not only hold for dynamic auctions but also for static, sealed-bid auctions (Adam et al., 2016, 2019; Teubner et al., 2015). Importantly, however, these studies found that the direction of the relationship depends on the underlying value model. In sealed-bid settings, for instance, higher arousal was associated with higher bids in common value settings (Adam et al., 2019; van den Bos et al., 2013), whereas the reverse was true for independent private value settings (Adam et al., 2016; Teubner et al., 2015). These differences between ascending and descending and between common and private value settings, respectively, can be explained by the

notion of arousal's risk-promoting effects. Placing higher bids in common value auctions is associated with a higher risk of paying too much. In first-price independent-private value auctions, risk averse bidders would generally place higher bids, because, by definition, risk averseness means that a bidder is willing to accept a lower profit when the outcome is more certain. By placing higher bids, winning the auction becomes more certain; in reverse, this means that a risk-taking bidder has a tendency to bid lower in a first-price auction, because this offers a higher profit in case the auction is won, but entails a higher risk of not winning the auction.

### Knowledge gaps and directions for future research

Over the past ten years, neurophysiological measurements have expanded our understanding of how emotions emerge during auction participation and influence bidders' decision making. Along the pathways captured by Adam et al. (2011b)'s emotional bidding framework, these studies have provided evidence for how specific elements in the auction environment (e.g., time pressure, presence of human bidders; Adam et al., 2012, 2015), individual auction events (e.g., placing a bid; Teubner et al., 2015), and learning the outcome of an auction (e.g., being announced as the winner; Delgado et al., 2008; van den Bos et al., 2013) lead to measurable changes in a bidder's emotional state (e.g., overall arousal) and the emergence of immediate emotions (e.g., frustration of losing, joy of winning). However, reflecting on the original framework also brings to light several knowledge gaps that have only received limited research attention so far.

To discuss these knowledge gaps systematically, we present a refined emotional bidding framework in Fig. 2. The refined framework captures the same cause and effect relationships as the original framework, as those relationships have been demonstrated to hold in neurophysiological studies (see Section 3). However, we reorganized and restructured the framework in order to achieve two main goals. First, as highlighted below, we consider it important that future research distinguishes more clearly between affective processes and cognitive processes when conducting research on emotions in electronic auctions. We therefore regrouped elements in the framework to clarify that the emergence of changes in the bidders' expected auction outcome and their expected emotions relates to a cognitive process, whereas the elicitation of immediate emotions and changes in the emotional state relates to an affective process. Second, as elaborated on further below, we argue that future research should consider in more detail the role and impact of biofeedback on emotions and bidding behavior in electronic auctions. To this end, we explicitly incorporate the concept of biofeedback in the revised framework and highlight it as a mechanism that can make a bidder's affective processes salient, thus creating a feedback loop between affective and cognitive processes.



**Auction environment** Despite important insights on the role of specific time characteristics (e.g., time pressure) and interaction characteristics (e.g., human bidders), little is known about which other factors in the auction environment elicit emotional responses. An important aspect are the properties of the item for sale (e.g., scarcity, stakes, and public interest). Being a dynamic pricing mechanism, auctions are most useful in markets where an item's precise value is not known ex-ante and difficult to predict. Otherwise, the marketer would avoid the transaction costs associated with the auction and directly post a fixed-price offer. Hence, there is an inherent uncertainty around the market price of the auctioned item(s). For perishable goods such as fish and cut flowers, this uncertainty stems from the difficulty to predict the supply and demand for fresh produce on a particular day due to their reliance on environmental factors (e.g., public holidays, weather conditions). While these perishable items are often sold in bulk by means of multi-unit auctions (e.g., Lu et al., 2019), high stakes items such as unique houses and pieces of art justify running individual auctions that can trigger broader public interest.

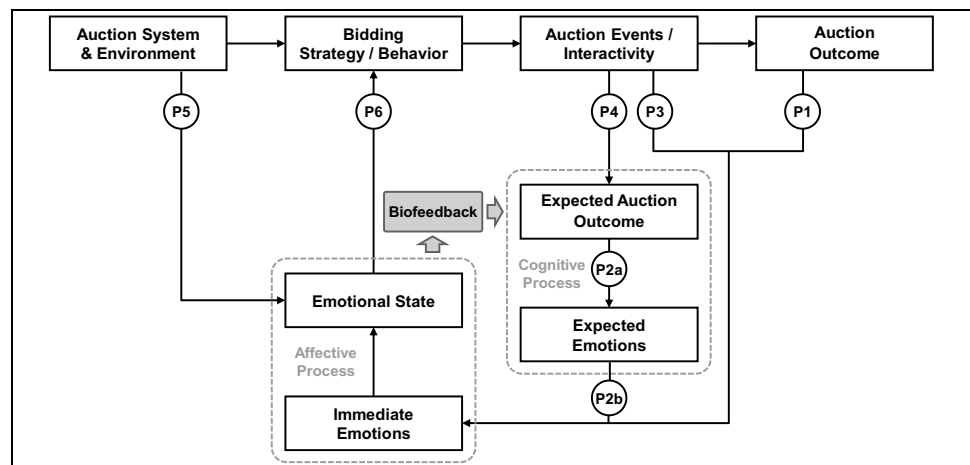
Although the competitive arousal model explicitly links scarcity, stakes, and public interest to the emergence of emotions (Ku et al., 2005), neurophysiological evidence on this matter is scant. Adam et al. (2011a) found that when bidders had a higher valuation for the item they also exhibited higher arousal. However, given that the experiment was not specifically geared towards this question, the authors were not able to disentangle whether this difference was (1) due to the higher amount of money at stake or (2) because the bidder also had a higher chance of winning the auction. Yet, evidence from survey methods hints at the important role of stakes. For instance, Ku et al. (2008) found that bidding behavior turned more aggressive when the stakes of the auctions were increased (by changing the conversion rates). Similarly, it is known that uncertainty and the presence of an audience drive arousal (Mullen et al., 1997; Urai et al., 2017). Understanding how these factors contribute to the emergence

of emotions during auction participation could hence provide important insights into the auction fever phenomenon (e.g., for housing auctions where stakes are generally high).

**Auction dynamics** The emotional bidding framework builds on the premise that the influence of emotions on bidding behavior is canalized through the construct of a bidder's (ongoing) emotional state. Hence, rather than assuming that the impact of emotions is constrained to the emergence of individual bursts of emotional processing over time, the framework takes into account that auction dynamics feed into an ongoing interplay between the elicitation of (short-lived) immediate emotions and a bidder's (ongoing) emotional state. In this sense, a bidder's emotional state may be the result of a complex series of events and emotional responses over time (e.g., market updates, changing high bidder status). Understanding the interplay of immediate emotions and the bidder's emotional state may explain how auction fever can build up over time in auctions with different levels of dynamics.

On a similar note, the majority of neurophysiological evidence on bidders' immediate emotions focuses on responses to the auction outcome (P1 – winning / losing; Delgado et al., 2008). Only limited research provides insight into the emergence of immediate emotions while the auction is still running. Further, while there is research on immediate emotions in response to auction events (e.g., Teubner et al., 2015), the existing studies were not able to disentangle which of the three pathways (P2–4) in the emotional bidding framework the observed immediate emotions can be attributed to. For instance, the changes in skin conductance that Teubner et al. (2015) observed in response to placing a bid could be explained by the joy of placing a bid (P3) as well as by a fear of losing triggered by thinking about the possible result of the bid just placed (P4). Considering the limitations of neurophysiological data, future research may adopt a multi-method approach that combines neurophysiological correlates with qualitative statements of bidders' lived experiences (e.g., using interviews;

**Fig. 2** Updated emotional bidding framework (adapted from Adam et al., 2011b)



Nichols & Flint, 2010). As we discuss next, we view multi-method approaches as a promising avenue for future research also more generally. However, NeuroIS studies may also devise experimental designs that are able to disentangle the different pathways, for example, by causing participants to think about certain auction outcomes during the auction process.

**Mixed-method research on the interplay between cognition and affect** Interestingly, only little research has considered the use of qualitative methods in understanding emotions in bidding behavior. Similarly, to the best of our knowledge, there have been no attempts to combine neurophysiological and qualitative methods to gain deeper insights into the interplay of human cognition and affect during auction bidding. Yet, qualitative assessments of auction participants' lived experiences have played an important role to instigate new pathways in auction research. A prominent example in this regard is the so-called utility of suspense hypothesis by Cox et al. (1982). This hypothesis stipulates that lower prices in Dutch auctions could partially be explained by bidders' tendency to derive hedonic value from the suspense they experience when watching the price drop. The authors referred to qualitative statements that subjects made after participating in their experiment, noting that they "enjoyed the 'clock experiment' more than the others because of the 'suspense of waiting'" (Cox et al., 1982, p. 27). Similarly, Johns and Zaichkowsky (2003, p. 320) noted that the "interview format may be most effective" in gathering information on how bidders approach and perceive auctions.

Taken together, neurophysiological measures and qualitative methods could provide important insights into how cognitive processes interact with the affective processes captured in the framework. For instance, this could provide insights into the tactics that bidders applied when the auction started, and how the course of events and the experience of emotions at different points of the auction process could have changed how bidders approached the later stages of the auctions. In this context, it would also be promising to consider neurophysiological measurements that have so far remained unused for understanding emotions' role in auction bidding. For example, eye tracking technology could be used to assess changes in bidders' pupil diameters as a measure for emotional arousal (Bradley et al., 2008; Mauri et al., 2011).

**Biofeedback** Since the inception of the original emotional bidding framework, technological advances have led to the development of neuroadaptive systems that provide biofeedback to the user (vom Brocke et al., 2013; 2020). Specifically, these systems employ neurophysiological measurements to provide users with insights on their own visceral processes. Biofeedback can assist users in gaining a better understanding of their own affective processes and to regulate the emergence and impact of emotions. Hence, system designers can now employ biofeedback to support bidders in recognizing and regulating

their physiological arousal levels. Astor et al. (2013b) showed that such biofeedback can support bidders in better recognizing changes in their emotional state and regulating it to yield lower arousal levels. Future research will need to investigate whether biofeedback is not only able to support bidders in regulating their emotional state but also whether this will lead to a change in bidding behavior (e.g., avoiding auction fever).

Furthermore, based on advances in machine learning, the ability of systems to assess human emotion and provide biofeedback to users will likely continue to improve. Specifically, the application of deep learning in affective computing has led to substantive improvements in the automatic recognition of human emotions from a range of modalities (Poria et al., 2017). In this vein, leveraging the interplay of human and artificial intelligence, user assistance systems may support bidders in balancing cognitive and affective processes during auction participation, and potentially overcome the detrimental impacts of auction fever. Further, the increasing accessibility and accuracy of wearable sensor technology (e.g., smart watches) can facilitate the proliferation of biofeedback systems beyond laboratory environments and facilitate adoption in the field. Complementarily, methods such as facial video-based heart rate assessment using consumer-grade cameras can further reduce the barriers to neurophysiological measurements in the field (Verkruysse et al., 2008).

In light of these new developments, both in terms of the technical ability to provide live feedback to auction participants, as well as with respect to advancements in real-time analytics, biofeedback emerges as an additional element that needs to be considered in the context of emotional bidding. Hence, we added biofeedback to the refined emotional bidding framework. In essence, biofeedback makes bidders consciously aware of their affective (unconscious) processes, and thereby enables the bidders to incorporate emotions directly into the cognitive process. In the bidding framework this links to the expected emotions that a bidder forms during the auction process, and which can then be used (more consciously) to regulate one's emotional state.

## Conclusion

By facilitating the exchange of products and services, electronic auctions have become an important pillar of an increasingly digitized economy. In order to effectively utilize electronic auctions, system designers need to have a profound understanding of how the design of the auction environment affects human bidding behavior and auction outcomes. This requires taking into account not only the cognitive aspects of human bidding behavior but also aspects associated with human affect. The conceptual work by Adam et al. (2011b)

provided a framework on how human affective processing may affect a bidder's emotional state and the emergence of immediate emotions during auction participation. Since its inception, new neurophysiological evidence became available which enabled us to evaluate the specific propositions made by the emotional bidding framework based on in situ measurements of emotions during auction participation. Based on these new NeuroIS studies, we confirmed the validity of the original emotional bidding framework, and also pointed to limitations where the existing studies could not disentangle the exact pathway through which the emotions emerge.

Importantly, the neurophysiological measurements also provided more detailed and nuanced insights, which were not specifically detailed in the original framework. Specifically, studies found that both integral (e.g., clock speeds) and incidental factors (e.g., affective imagery) in the auction environment may affect a bidder's emotional state which in turn affects their bidding behavior. Depending on the auction mechanisms and the type of product being sold, higher arousal may result in higher or lower prices. Further, placing a bid in an auction is an event that triggers immediate emotions, with higher amounts of money yielding stronger intensities. Finally, both winning and losing an auction triggers immediate emotions, the intensities of which depend on the auction mechanism, the type of interaction partner, and the amount of money at stake. These insights would not have been possible without in situ measurements (e.g., in response to placing a bid, in the moment of seeing the auction outcome). In fact, one of the NeuroIS studies listed in Table 3 compared the neurophysiological measurements of the bidders' emotional state with those reported by the participants themselves through questionnaires (Adam et al., 2016). The authors found that participants were often unaware of their heightened emotional state during the auction, and thus, according to self-report measures alone, no treatment differences could have been detected.

Based on these new insights we suggest a refined emotional bidding framework that may inform future research. We identified several knowledge gaps that warrant more detailed investigation. In particular, we suggest to explicitly consider the effects and role that biofeedback can have on the interplay between cognitive and affective processes, and how this would impact bidding behavior. First studies are indicative that biofeedback may play a crucial role in leading to better auction outcomes, but ultimately this is still an open and in our view important research question. Therefore, the refined emotional bidding framework now incorporates the element of biofeedback explicitly.

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