Methodology – ODD Protocol

To accurately and easily describe the following Agent-Based Model, I will follow the ODD Protocol (Grimm & al, 2006), allowing for easier interpretation, and assessment of this model. Another key advantage of following an ODD protocol is to make it easier for potential researchers to re-use or re-implement this model. The ODD Protocol follows a three-steps structure, to structure the presentation of Agent-Based models: Overview, Design Concepts and Details.

Overview – Context and general Information

- *Purpose:*

The purpose of this model is to understand the "competitive arousal model" in an Art Auction i.e. how some factors, specific to auction dynamics – in particular Rivalry and Time Pressure – increase arousal levels of bidders and affect Auction Fever. In particular, the goal of this model is to highlight the two-steps process leading to rising bids' amounts, above thresholds bidders set for themselves: 1) "Competitive Arousal" can trigger the "Desire-to-win" (i.e. It becomes more important for bidders to beat other competitors rather than to acquire the specific artwork) 2) How the "Desire-to-win" drives bidding amounts up, above individual thresholds individuals set for themselves. A secondary goal is to test the effect and extent of both the number of bidders and the level of the opening bid on the Auction Fever effect.

- *State Variables & Scales*

This model describes a bidder market with two hierarchical levels: individuals and the environment. Individuals are divided into two groups: 1 Auctioneer who sets the asking-price for the artwork at each bidding round and Bidders with different value-assessments for the artwork (perceived value of the work of art) and different desires to win the auction (how much they are willing to pay extra to beat their competitors and to "win" the auction). The maximum amount bidders are going to bid is a function of personal value-assessments and desires-to-win and is the main attribute which determines the bidding behavior (Table 1).

Table 1 - Overview of processes, parameters and default thresholds of the Competitive Arousal Model	
Parameter	Value
Population Interval	2 - 20
Time Pressure (as a percentage of bidders' value-assessment)	
- Low Time Pressure	< 0,8
- High Time Pressure	>= 0,8
Rivalry (as a function of the number of bidders)	
- Low Rivalry	>= 8
- Medium Rivarly	5-7 bidders
- High rivalry	3-4 bidders
- Bidding war	2
Desire-to-win changes (incremental amounts in euros) & overbid limits (max number of times bidders would overbid in this scenario)	
- Low Time Pressure x Rivalry & High Time Pressure x Low Rivalry	
Desire-to-win changes	0
- High Time Pressure x Medium Rivalry	
Desire-to-win changes	0.7% of v-a
Overbid limits	1
- High Time Pressure x High Rivalry	
Desire-to-win changes	1.0% of v-a
Overbid limits	3
- High Time Pressure x Bidding war	
Desire-to-win changes	0.05% of v-a
Overbid limits	7

These default values have been selected after the findings of the Literature Review. Ku, Malhotra & Murnighan (2004) made useful predictions about how bidders would react when faced with other bidders. In particular, they found that in a low rivalry setting, with more than 8 bidders, individuals would be unlikely to overbid, whereas, the number of active bidders is negatively correlated with the number of overbids. As

such, they drew a distinction between different settings: Low Rivalry (more than 8 bidders), Medium Rivalry (more than 5 bidders), High Rivalry (3-4 bidders) and a bidding war (2 bidders).

Building on this analysis, Adam, Krämer & Müller (2015), using pairwise comparisons found that a Low Time Pressure (LTP), even when coupled with High Rivalry (HR) had little impact on final prices levels. Thus, in this model, the desire-to-win is not affected when Time Pressure is low. However, a High Time Pressure, when coupled with Medium Rivalry increases average bidding amount by 0.7%. Therefore, the desire-to-win increases bidding amounts by 0.7% of individual bidder's value assessments. As bidders in average overbid 1.5 times for each item (Ku, Malhotra & Murnighan, 2004), I decided to set the maximum number of overbids to 1 in this particular scenario. In the scenario of High Time Pressure coupled with High Rivalry, the three economists found that the average bidding amount increases by 2.9%. As bidders in this scenario are more likely to overbid more than once, I set the maximum number of overbids to 3. The 2.9% increase of average bidding prices, spread over three rounds of overbidding and incremental revaluation of their desire-to-win can be expressed by a 1% increase in the value assessment, each round. Finally, the last scenario is the one of the bidding war, where bidders are likely to submit multiple overbids (Ariely & Simonson, 2003). This hypothesis is translated in this model by a high number of overbids possible, up to 7.

Finally, as the model doesn't count for the passing of time, which would only be accurate if bidders did not bid every round (Hammon & Morril, 2016), the High Time Pressure can be translated as a threshold above which individuals feel like they are running out of time in this specific auction. This hypothesis means that when the asking price is already high in their value-assessment, and the remaining room for bidding is limited, bidders would feel a form of High Time Pressure. Therefore, we set the High Time Pressure condition at 80% of individuals' value-assessments, meaning that when the asking-price exceeds this threshold, bidders feel a High Time Pressure.

The environment represents a specific auction for a particular item. It is both characterized by the specificities of the artwork brought up to auction: the high and low estimates of the price and the asking bidding price and also by state-variables: number and list of bidders present. The population is composed only of active bidders. If a bidder stops bidding, He turns red and cannot be re-allowed into the auction.

- *Process Overview and Scheduling:*

The model demonstrates a very simple bidding market where buyers try to acquire a desired artwork at the best price in a competitive environment. The model proceeds in discrete time steps using bidding rounds (ticks). Each round or step (recorded by the number of ticks), the bidders decide to either bid or drop out. If the asked amount is below the bidder's value assessment, they'll bid. If it's higher, the decision depends on their desire-to-win, if it goes beyond their max bidding amount (value-assessment + desire-to-win), they drop out. Then each bidder individually decides to either raise or not their desire-to-win according to the position of the current asked price in their value assessment (Time Pressure) and the remaining competition. For instance, if there are 8 bidders remaining (small competitive arousal), they are unlikely to up their desire-to-win. But if there are only 2 bidders left, they are more likely to enter a bidding war and up their desire-to-win.

Each round, if more than one bidder remains and therefore the item has not yet been acquired, the auctioneer increases incrementally the asking-price for the item. The auctioneer usually raises the asking-price by the same amount every time. However, the potential new asking-price may sometimes exceed the highest maximum bidding amount. For the auctioneer, this would mean, that he cannot sell the item at this specific asked price, and that he misses his chance to sell the item as some bidders are still interested in buying the item for a significant, even though smaller, amount. Thus, if raising the asking-price by the same amount as before means to exceed the highest maximum bidding amount, the auctioneer raises the asking-price by a smaller amount at an equal distance between the previous asking-price and the highest maximum bidding amount.

The market will run through rounds until only one bidder remains. The sale value of the Item is the last bidded amount.

The individuals bidding cycle is depicted in Fig. 1.

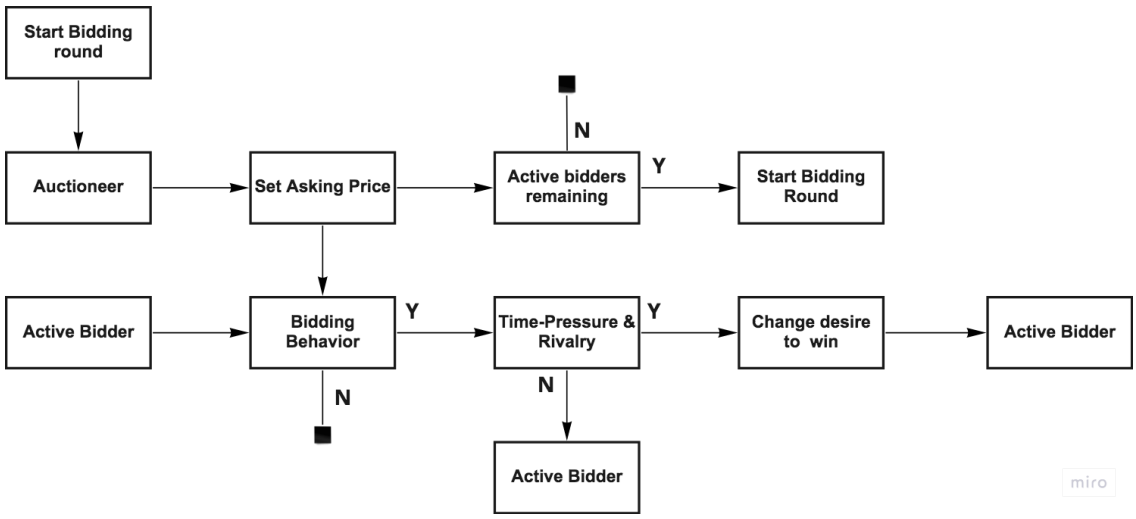

Fig. 1. Bidding cycle of the model, showing the decisions of bidders and auctioneers each round, depending on the maximum amount bidders are willing to pay, and what processes cause this amount to change.

Design concepts – Strategic considerations

- *Emergence:* High levels of competitive arousal (emotional state leading bidders to bid past their own personal limits and their own value-assessment) emerge from the behavior of the individuals i.e. from their revaluation on their value-assessment based on their desire-to-win. The individual's reassessment of their desire-to-win is entirely represented by empirical rules, describing for example the number of bidders, current level of the asking price… Rivalry and Time Pressure are thus not modelled explicitly even though they can be drawn from existing empirical rules.

- *Adaptation:* the bidders' adaptive trait is their desire-to-win, which responds to the changes in their environment, and especially the changes of Social Competition.

- *Objectives:* The agents' objective is modelled explicitly at the beginning of the model and can be summarized as follows: To maximize their personal utility, which is to acquire the desired item at the amount matching, or inferior to, their value assessment. However, the model wants to show how individuals derive

from this primary objective, and how a second implicit objective arises, which is to beat other competitors. This second objective is translated in the model by changes in individuals' desires to win.

- *Sensing:* Bidders are assumed to know their own value assessment and desire to win, but also the high and low estimates of the item up for sale, the asking price and the level of competition (number of other active bidders). Auctioneers know their asking price but they are also supposed to know the high and low estimates and the level of competition.

- *Interaction:* Three types of interactions are modeled explicitly. If more than one bidder remains at the end of a bidding round, the auctioneer increases the asking price incrementally, and Rivalry and Time Pressure increase the desire to win of remaining bidders. Two interactions are modelled implicitly, the Bidders and auctioneers communicate about the current level of the asking price and bidders exchange information about who is still actively bidding.

- *Collectives:* Individuals are grouped into two collectives: the auctioneer, in the number of 1 and bidders, who are subsequently divided into two groups: active bidders and bidders who have left the auction.

- *Observation:* For model testing and analysis, two tracking variables were observed and recorded process by process, 100 times each scenario: the difference between the last bid and the highest value assessment (the variation is expressed as a percentage of the initial value assessment) and the average number of overbids. These indicators were compared to results found in Auction Fever researches i.e. the difference between value assessments and bidding amounts in Competitive environment is of 2.1% in average (Erhart, Ott & Abele, 2006) and the average number of overbids is 1.5 per bidders (Ku, Malhotra & Murnighan, 2004). For further analysis, these tracking variables were compared and plotted against variations in the number of initial bidders and open bid levels.

Details – Technical Details

- *Initialization:*

Most variables in the model are not fixed but take the form of inputs to be configured at the beginning, every time the model is run. Estimate Intervals can take any value, as long as the low estimate is inferior and relatively close to the high estimate. The number of bidders can be set between 2 and 20 bidders to relatively match real auction conditions. Their value-assessment is set at random between the high estimate and half of the high estimate.

The environment is initially occupied with a single auctioneer. The starting asking-price is set in accordance with the common implicit rule among auctioneers, at 30-40% of the Fair Market Value (Rickards, 2014). Thus, I set the starting-asking-price at 35% of the FMV. The Fair Market Value is set at the middle between the high and low estimate. The auctioneer approximately sets the increment at 10% of the starting asking price (Rickards, 2014), which is therefore the increment value set in this program.

- *Input:*

In this competitive arousal model, all environmental conditions are drawn from pairwise comparisons between different levels of Time Pressure and Rivalry (from Adam, Krämer & Müller, 2015 after Ku, Malhotra & Murnighan, 2004).

Input data could also be generated from new source files generated in Art auction environment to reach more accuracy in this model.