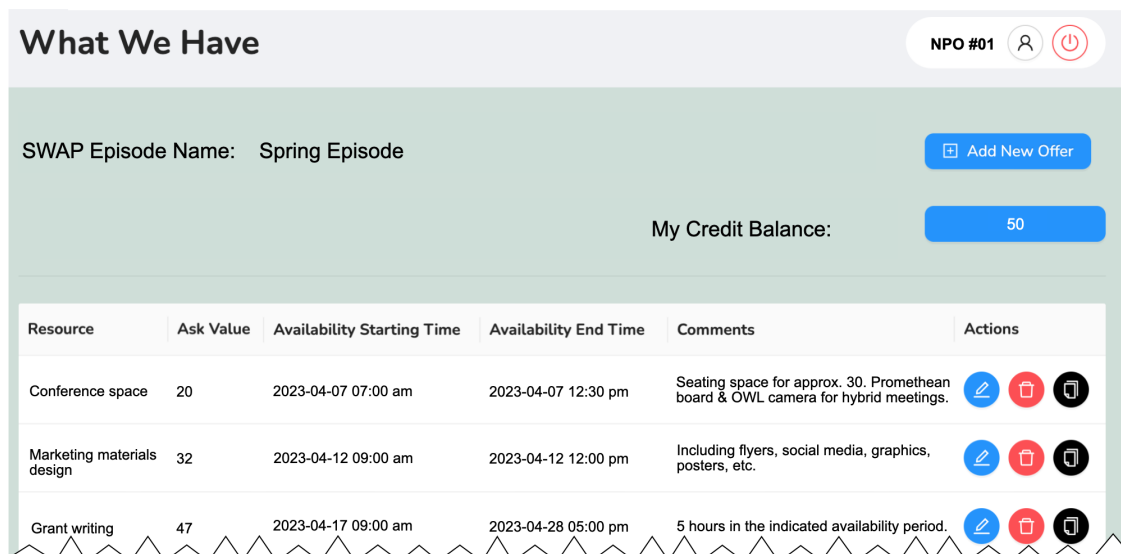


Appendices

A. The SWAP Hub

We provide more context on the online platform, the SWAP Hub, regarding its major functionality and user interfaces (UIs) of the three main rounds. Figure 10 depicts what NPO #01 is presently offering. Figure 11 depicts what NPO #01 is presently bidding on and updating the bid value. Finally, Figure 12 depicts what NPO #01 is giving and receiving according to the exchange, or matching results. We iteratively design and refine the SWAP Hub UI. Prior to deployment, we let the participating NPOs express their concerns about learning a new technology amidst busy schedules, and thus identified “lower barrier to access” as a key value. More than 15 NPOs had voluntarily tried out the SWAP Hub. We observed how they completed multiple practice episodes, and collected their feedback during and after the user experience testing. The user experience data reveal that the SWAP Hub UI is relatively easy to understand and convenient to use. Indeed, during deployment and under instruction, all participating NPO directors and staff correctly completed the major functions of posting an offer, placing a bid, and viewing results within 15 minutes. After deployment, we hold reflection sessions after each SWAP episode to gather feedback from NPO users. We then analyze and incorporate into UI updates, such as a Chat Channel feature integrated after users expressed that they wanted an access to communicate their foreseeable needed resources.

Figure 10: The “What We Have” view in SWAP allows NPOs to offer resources during the offering round.



Resource	Ask Value	Availability Starting Time	Availability End Time	Comments	Actions
Conference space	20	2023-04-07 07:00 am	2023-04-07 12:30 pm	Seating space for approx. 30. Promethean board & OWL camera for hybrid meetings.	  
Marketing materials design	32	2023-04-12 09:00 am	2023-04-12 12:00 pm	Including flyers, social media, graphics, posters, etc.	  
Grant writing	47	2023-04-17 09:00 am	2023-04-28 05:00 pm	5 hours in the indicated availability period.	  

Figure 11: The “What We Need” view in SWAP allows NPOs to bid on resources during the bidding round.

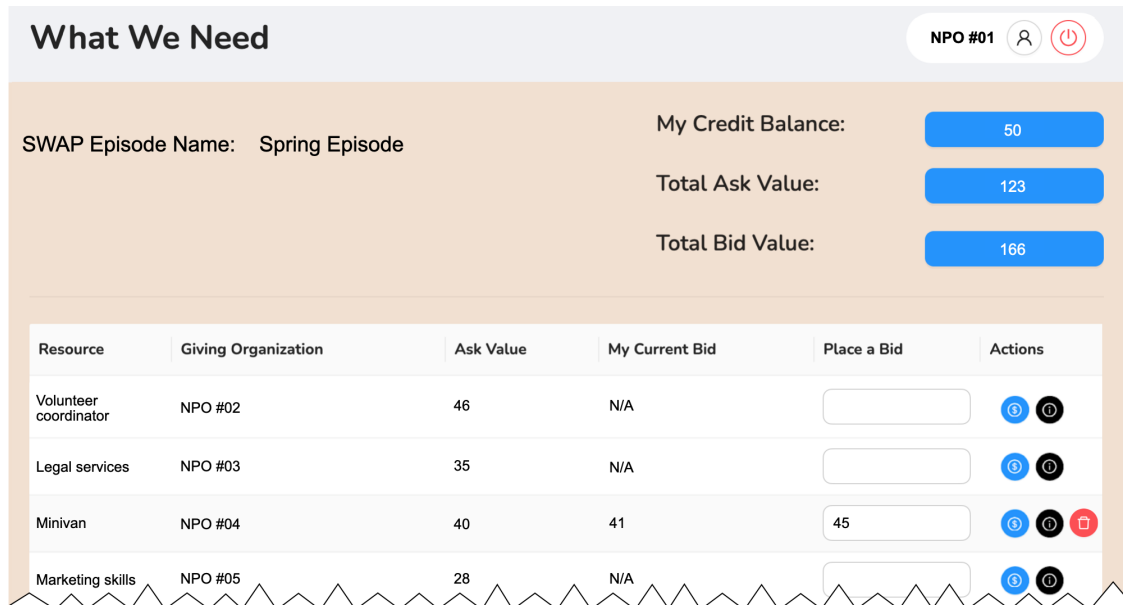
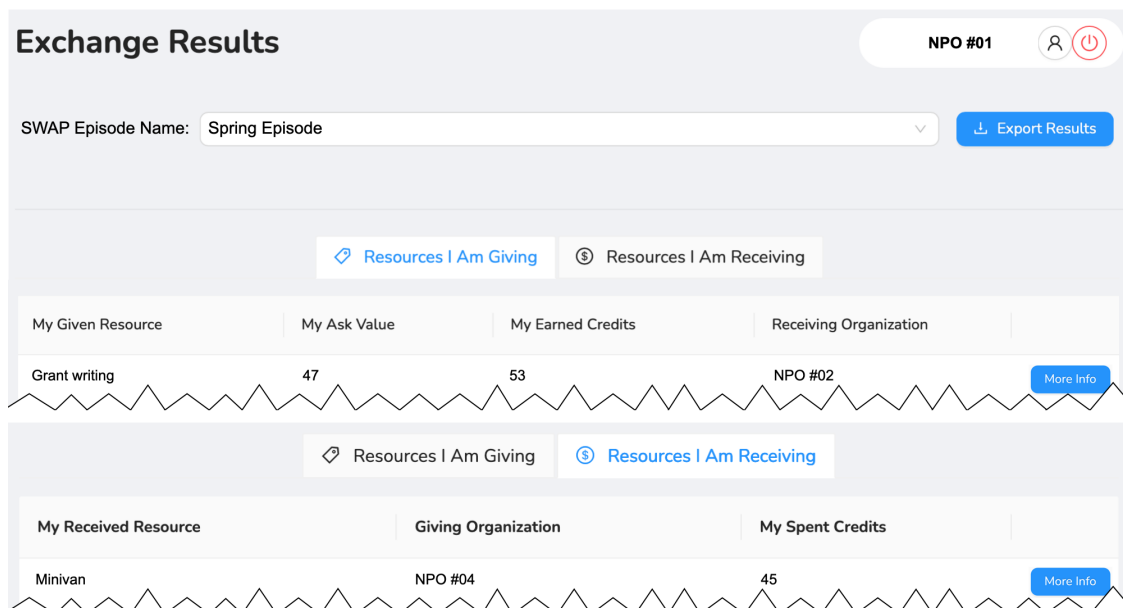


Figure 12: The “Exchange Results” view in SWAP publishes exchange results for receiving and giving.



B. Additional Simulation Experiments: Two Models with Varied NPO Behaviors

To exploring that the distinct offering behaviors impact matching results for each market context-model pair, we vary the number of resources offered per NPO from low, conservative levels (L1) to high, generous levels (L3) showed in Table 6. The controlled attributes follow the settings in Table 4 Controlled Attribute.

Varied Factors	Levels: L1, L2, ...		
	Low (L1)	Medium (L2)	High (L3)
# of Offers per NPO	$\Pr(\{0,3\})=0.4^{**}$ $\Pr(\{1,2\})=0.6$	$\Pr(\{0,1,9,10\})=0.2$ $\Pr(\{2,8\})=0.15$ $\Pr(\{3,4,5,6,7\})=0.65$	$\Pr(\{7,10\})=0.4$ $\Pr(\{8,9\})=0.6$
	Low (L1)	Medium (L2)	High (L3)
# of Bids per NPO*	$\Pr(\{R-1, \dots, R+2\})=1$	$\Pr(\{R-1, \dots, R+2\})=0.5$ $\Pr(\{R+3, \dots, 2R\})=0.5$	$\Pr(\{R+3, \dots, 2R\})=1$

*For defining probabilities, let R denote the positive number of resources offered by the respective NPO; when $R = 0$, the minimum number of bids is 0.

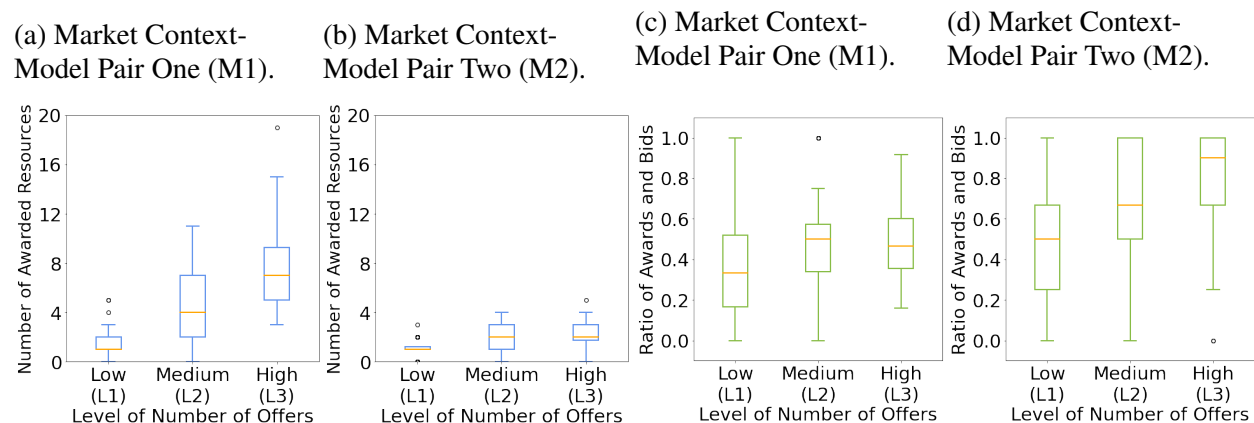
**The probability that an NPO offers 0 or 3 resources is equal (discrete uniform), and likewise for other discrete variables in each level.

Table 6: Varied factors and levels regarding offer and bid behaviors and cohort size.

We study the matching outcomes for the two market context-model pairs, using “M1” and “M2” for brevity in the ensuing discussion. The following analysis assumes that participants in both M1 and M2 share the same understanding of valuing resources, such as ask values and winning bid values.

By varying the number of offers from conservative to generous, we identify the advantages and limitations of each market context-model pair. Figures 13a and 13b show that, for both M1 and M2, across three offering levels per NPO, greater engagement by NPOs to generously offer resources promotes more awarded resources both for each NPO, as well as collectively. The count of awarded resources per NPO increases significantly in M1, while it grows only modestly in M2. This occurs because the total bid value is not bounded in M1. It would likely have exceeded the balance, whereas bids are restricted in M2 by the balance cap. Figures 13c and 13d display the distributions of the ratio of awarded resources to bids per NPO in

Figure 13: Distributions of per NPO number of awarded resources and ratio of awards and bids .



M1 and M2, respectively. Overall, when NPOs are not conservative in offering their available resources, the ratios increase in both M1 and M2. While at each offering level, the median ratio in M1 is consistently lower than in M2. These observations indicate that M1 allows participants to place as many bids as desired, yet this leads to greater uncertainty in their ability to secure resources. This is due to a lack of sufficient earned credits to afford placed bids, as well as increased competition. Conversely, M2 excels in assisting NPOs to be awarded the majority of their bids. Because bids are limited to the balance, NPOs in M2 place bids more judiciously according to their needs, resulting in a higher rate of awarded bids. Our experiments reveal that the distinct operational processes and optimization approaches of M1 and M2 provide options for cohorts.

In addition, the experimental observations suggest that with any option chosen, it is important to raise awareness of the temporal availability of resources, such as by encouraging NPOs to embrace asset mapping which we employ across cohorts, assisting each participant to reflect on and name their assets.

More extensive experiments and discussions on NPO offering and bidding behaviors, their influence on exchange results, and recommendations to improve NPO experiences are available in an earlier study (Huang et al. 2023). For brevity, we omit those discussions.

C. Additional Simulation Experiments: Credit Redistribution Performance in Two Cohort Scenarios

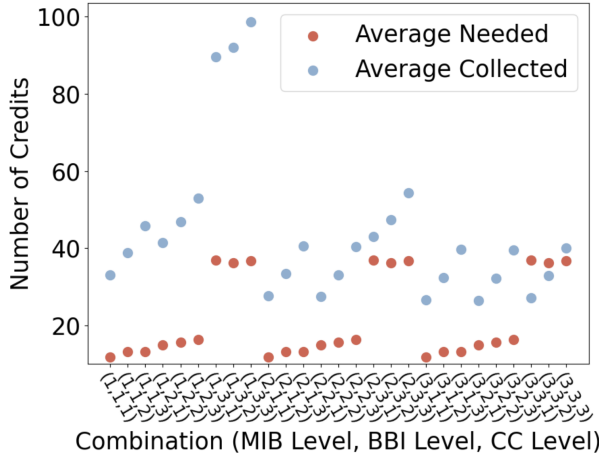
The findings of our experiments are reflected in and applied to two concrete cohort scenarios. The first scenario involves a newly established cohort where NPOs are learning about one another and understanding their respective resource needs. In this scenario, NPOs may engage conservatively, offering fewer (e.g., no more than three) resources and placing fewer bids (e.g., no more than five) per episode. With limited offers and bids, the total number of exchanges remains low, making it unlikely for NPOs to accumulate excessive credits. Meanwhile, an NPO may easily end up with a low credit balance by failing to offer resources that meet the needs of other NPOs while themselves spending to acquire resources.

Figure 14a depicts the MIB-CC combinations across three BBI levels for proposing concrete redistribution rules for the newly-established cohort scenario. We see that high MIB and light CC often fail to collect sufficient credits, resulting in an average amount of collected credits below what is needed (third and second right most outcomes in Figure 14a). To address market imbalances and provide sufficient support for NPOs in market conditions similar to this first scenario, it is recommended to set MIB to L1 and CC to L2 or L3.

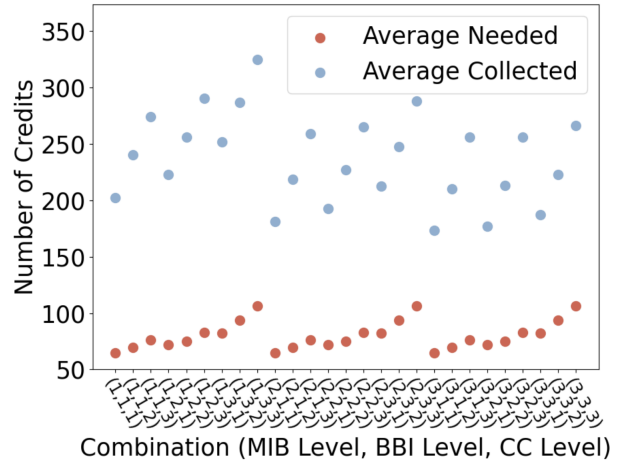
The second scenario, depicted in Figure 14b, involves a well-established cohort where NPOs are familiar with market dynamics. This market is characterized by a higher volume of offering, bidding, and resource exchanges, resulting in a thick and active market. Consequently, sufficient credits are always collected from CC and MIB to protect against monopolies and assist NPOs with low balances, regardless of BBI, CC, or MIB levels (Figure 14b). In this scenario, the recommended credit redistribution rules are to conservatively

Figure 14: Examining redistribution policies for two concrete cohort scenarios.

(a) Redistribution for newly-established cohort.



(b) Redistribution for well-established cohort.



set MIB to L3 (high) and CC to L1 (light) to maintain effective operations while supporting active resource sharing.

D. Computational Complexity of the Input-Output Balance Exchange Model

Proposition 1 *The Inflow-Outflow Balance Exchange Model (1a)–(1d) is strongly NP-hard.*

Proof. The problem is strongly NP-hard via a polynomial reduction from the strongly NP-complete 3-PARTITION problem, which asks, given m bins, a positive target integer B , and a set of $3m$ positive integers $\mathcal{N} = \{s_1, \dots, s_t, \dots, s_{3m}\}$ with $\sum_{t=1}^{3m} s_t = mB$ and $B/4 < s_t < B/2$ for all $t = 1, \dots, 3m$, whether $\mathcal{N}$ can be partitioned into m disjoint triples each summing to B . Given an instance of 3-PARTITION, we can determine if a valid partition exists by solving a particular instance of (1a)–(1d) constructed as follows. Let $\mathcal{B}$ denote the m bidders and $\mathcal{S}$ the $3m$ providers. For each $t = 1, \dots, 3m$, create exactly one provider $i_t \in \mathcal{S}$ offering a single resource $k_t \in \mathcal{R}_{i_t}$ corresponding to the integer s_t . Only providers offer resources; bidders offer none. Assign each bidder $j \in \mathcal{B}$ credit $c_j = B$. Set ask values $r_{i_t}^{k_t} = 0$ for all resources. For every bidder $j \in \mathcal{B}$, set the bid on resource k_t of provider i_t to $b_{i_t,j}^{k_t} = s_t$.

By (1b) each resource is assigned to at most one bidder. Because bidders make no offers, the earned-credit term on the right-hand side of (1c) is zero, and the constraint becomes $\sum_{t=1}^{3m} s_t x_{i_t,j}^{k_t} \leq B$ for each bidder $j \in \mathcal{B}$. With ask values of zero for all resources, the objective (1a) simply maximizes the total assigned value, $\sum_{t=1}^{3m} \sum_{j \in \mathcal{B}} s_t x_{i_t,j}^{k_t}$. The total available credit is $\sum_{j \in \mathcal{B}} c_j = mB$ and the total size is $\sum_{t=1}^{3m} s_t = mB$, so the objective value is at most mB , with equality if and only if all resources are assigned and the budget of every bidder is exhausted. The bounds from 3-PARTITION ($B/4 < s_t < B/2$) ensure that any bidder exhausting their credit of B must be assigned more than two resources (so sum is not less than B) resources

and less than four resources (so sum does not exceed B), hence exactly three. An optimal solution to this SWAP instance is thus equivalent to a valid 3-partition. As the reduction is polynomial, this establishes strong NP-hardness. ■