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OPERATIONS RESEARCH
Vol. 00, No. 0, Xxxxx 0000, pp. 000–000
ISSN 0030-364X, EISSN 1526-5463

Submitted to *Operations Research*

Community-Oriented Market Design for Nonprofit Resource Exchange

Weixiao Huang,[a] Carlos Morel Figueroa,[b] Arjun Venat,[a] Sarah E. Stanlick,[a] Yunus D. Telliel, [a] Alexander Teytelboym, [c] Jennifer A. Pazour, [b] Andrew C. Trapp, [a,b]

[a]Department of Data Science, Department of Computer Science, Department of Integrative and Global Studies, Department of Humanities & Arts, Business School, Worcester Polytechnic Institute, Worcester, Massachusetts 01609 whuang2@wpi.edu, avenat@wpi.edu, sstanlick@wpi.edu, ydtelliel@wpi.edu, atrapp@wpi.edu;

[b]Department of Industrial and Systems Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180 morelc2@rpi.edu, pazouj@rpi.edu, trappa@rpi.edu;

[c]Department of Economics, University of Oxford, Oxford OX1 3UQ, United Kingdom alexander.teytelboym@economics.ox.ac.uk

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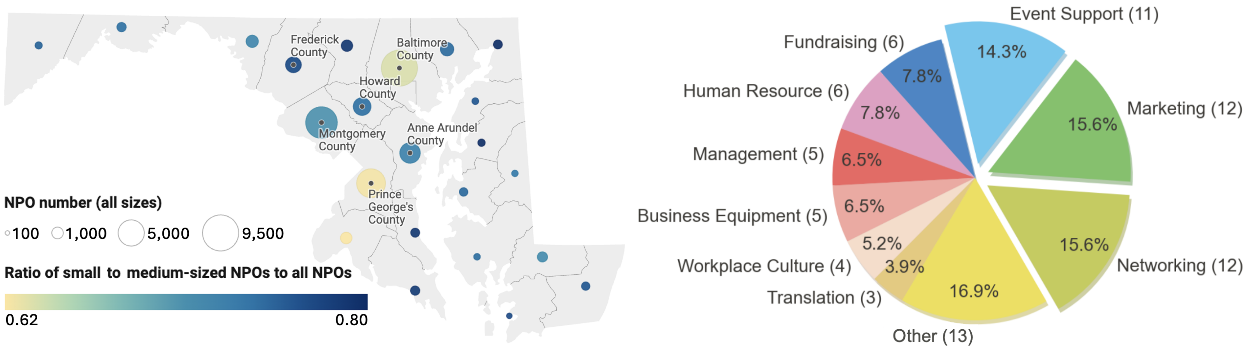
Abstract. Nonprofit organizations (NPOs) face persistent challenges in securing the resources they need in pursuit of their missions. Yet, because NPOs plan their use of physical assets, talent, skills, and others in advance, their needs often fluctuate over time, creating opportunities for resource exchange among NPOs. We introduce SWAP (*Sharing With A Purpose*), a novel market that enables NPOs to obtain resources from other NPOs by offering their own. SWAP consists of three key components: (1) market formation to create NPO resource-exchange cohorts, (2) auction-based multilateral exchange with virtual currency using integer optimization to maximize collective surplus, and (3) a co-designed and iteratively refined process that builds participation, trust, and community. Simulated experiments demonstrate optimized market outcomes, computational efficiency of the optimization models, and the benefits and effectiveness of virtual currency redistribution policies. Real-world deployment with NPO cohorts based in Maryland, USA, has succeeded in facilitating numerous, wide-ranging resource exchanges, revealing that SWAP can provide NPOs with opportunities to generate greater value from existing resources. Nonprofit directors report strengthened collaboration, new thought partnerships, and enhanced community ties. These results reveal SWAP's potential to strengthen community impact in the nonprofit sector.

Key words: Market Design; Auctions in Practice; Integer Optimization; Resource Allocation; Nonprofits

Figure 1: Distribution of nonprofits and reported resource gaps in Maryland, USA.

(a) Distribution of NPOs by counties. (b) Distribution of resources needed by NPOs.



1. Introduction

Nonprofit organizations (NPOs) strengthen the fabric of our society by driving community development and empowering individuals. At the local, national, and global scale, millions of NPOs with distinct missions lead initiatives in welfare, healthcare, education reform, cultural dissemination, civil society, environmental conservation, and more (Anheier 2014, Faulk et al. 2021). In the United States, the nonprofit sector has become a major economic and social force, employing the third largest workforce with approximately 12.5 million jobs (Salamon and Newhouse 2020) and relying on an immense volunteer base—about 63 million Americans volunteered an average of three-and-a-half hours per week (Conrardy 2021, Ensor 2023, Nonprofits Source 2024).

One of the greatest challenges NPOs face in fulfilling their missions is identifying and securing resources, including physical, human, social, and economic assets (Camper 2016). Despite 85% of nonprofit leaders reporting increased demand for their services, 36% ended 2024 with an operating deficit, the highest rate in 10 years of survey data (Nonprofit Finance Fund 2025). Nonprofit employees often lack the tools and professional support needed to handle their work (McGinnis Johnson and Ng 2016, Knapp et al. 2017), which results in high employee turnover. Moreover, while numerous entities financially support the nonprofit sector, funds are often earmarked for specific purposes, limiting NPOs' flexibility and access to unrestricted capital (Privett and Erhun 2011). These effects severely impact the quality and quantity of services NPOs can deliver (Saxton et al. 2014, Berenguer and Shen 2020, National Council of Nonprofits 2023).

To better study the challenge, we examine the distribution and organizational scale of NPOs located in Maryland, USA (Figure 1a), and we conducted a study to understand the type of resource gaps that exist (Figure 1b). Maryland is home to more than 40,000 501(c)(3) organizations, with a particularly high concentration, nearly 10,000, in Baltimore County, including Baltimore City. These NPOs pursue diverse missions, providing healthcare, social assistance, and community development, with at least 62% of NPOs in each county categorized as small- or medium-sized, operating with limited staff, assets, and revenue (Newhouse 2021, Cause IQ 2025). While specific to Maryland, these patterns also reflect broader national trends.

We interviewed 15 leaders from small- and medium-sized Maryland NPOs to understand specific resources that would meaningfully support their administrative, operational, and service activities. These NPO leaders identified a wide range of resources, with the most in-demand resources being categorized under *Networking*, *Marketing*, and *Event Support* (Figure 1b). Some of these resources were intangible resources, which included “leadership connections”, “marketing research”, and “help in publicizing events”, while other tangible resources included “office supplies” and “space for training programs”.

Furthermore, to gain a deeper understanding of how these types of resource needs unfold in practice, we surveyed a set of small to medium-sized Maryland-based NPOs (Harrell et al. 2021). Many NPO activities are *planned in advance*, such as annual fundraisers, community programs, grant applications, reporting, and outreach events. The demands on resources created by these activities *fluctuate over time* and *are often uncorrelated among NPOs*. Hence, resource-scarce NPOs may, at times, identify underutilized or even spare resources across seasonal, monthly, or even weekly periods, yet lack the ability to adjust staffing or physical capacity to meet shifting service demands. In our work with NPOs, we have observed, for example, one NPO needed inventory pickup support for an activity the following weekend and was willing to offer the time and talents of a social media strategist. Another NPO had available delivery capacity and needed assistance with social media promotion for an important event the next month. This reflects a general pattern of *reciprocity* advocated by nonprofit thought leaders: there is a great opportunity for NPOs to gather together to identify needs and available resources, and to share among themselves resources needed for their collective missions (Brothers 2021).

Yet, even among NPOs interested in sharing, we are not aware of any practical mechanism that jointly elicits needed resources (that is, *needs*) and short- or long-term available resources (that is, *haves*) and clears exchanges efficiently. Consequently, many resources sit underutilized within some NPOs, while other NPOs must purchase similar resources on their own. Numerous studies on mathematical optimization-based matching and allocation methods in the nonprofit sector offer valuable precedents across a wide range of contexts (Chick et al. 2017, De Boeck et al. 2020, Wiratchotisatian et al. 2022, Bennouna et al. 2023, Jacquillat et al. 2024). Our resource-exchange context differs from prior studies: instead of focusing on bipartite matching, each NPO in our context simultaneously acts as both a resource buyer and a resource seller. This dual role introduces additional complexities, as an NPO’s behavior in one role can impact its outcomes in the other.

We propose the SWAP (*Sharing With A Purpose*) system, designed to enable resource sharing for small to medium-sized nonprofits. The SWAP system consists of three key components: market formation, multilateral exchange, and community co-design. Market formation defines the core principles and components of a nonprofit resource-exchange market and informs the essential steps to form such a market, or *cohort*. The multilateral exchange defines an *episode* starting with a virtual *SWAPcredit* currency (re-)distribution, an offering round, a bidding round, followed by a matching round that solves a matching determination problem through integer optimization, and concluding with a round of actual exchanges. The multilateral exchange is operated through our deployed web-based platform, the *SWAP Hub*, where participating NPOs offer their haves, bid on needs, and review exchange outcomes. The *SWAP collective* is composed of researchers, project coordinators, NPO specialists, and legal professionals, and actively engages and builds sustainable connections with NPO stakeholders. A community co-design process shapes the understanding and design decisions of SWAP and ensures the voices of NPO stakeholders are heard and used to improve the SWAP system.

Our work makes the following contributions. To the best of our knowledge, SWAP is the first sharing system that facilitates resource exchanges whereby organizations can obtain resources by offering their own. The embedded technology of multilateral exchange determination establishes two practical market contexts with integer optimization models incentivizing market thickness and exchanges, and the corresponding SWAPcredit (re-)distribution policies support vulnerable participants and discourage monopolistic dominance. SWAP arose out of long-standing partnerships with nonprofit leaders and the rooted co-design process brings together the SWAP collective and NPO stakeholders to inform contextually appropriate designs and refinements, and to develop and expand a collaborative community. We demonstrate the effectiveness and efficiency of SWAP through simulated experiments, as well as active and ongoing markets with NPOs. The SWAP system has been deployed via a controlled pilot to NPOs in Howard and Baltimore Counties in Maryland, resulting in over 70 resource exchanges that benefit NPOs across a range of activities that include marketing, fundraising, and service provision. These participating NPOs are small to medium-sized NPOs, operating across diverse service missions including housing, financial, workforce, veteran assistance, tool and equipment support, and environmental sustainability. As co-design partners, these NPOs actively contribute to SWAP's design, feature development, user testing, and refinement. This work demonstrates that a well-designed resource sharing platform for NPOs can enable a new way for NPOs to obtain resources, and evidence from SWAP's deployment shows that such a system can also promote trust and collaboration, empowering collective impact within the nonprofit sector.

The remainder of this article is organized in the following manner. Section 2 provides background on existing work on resource allocation and procurement in the nonprofit sector, auction and matching market design in the nonprofit sector, and community-based research. Section 3 formally introduces the SWAP system, including market formation, multilateral exchange, and community co-design. Section 4 describes the match determination problem, the market contexts, and the corresponding mathematical optimization models. Section 5 presents computational experiments with simulated data to explore the matching performance and computational efficiency of our markets and models, and the benefits and effectiveness of virtual SWAPcredit currency redistribution policies. Section 6 reveals the impact of the SWAP system in the real world through the analysis of quantitative and qualitative data collected from SWAP operations in practice. Section 7 concludes with a summary of our work, including future research directions.

2. Literature Review

We review prior studies concerning resource allocation and procurement, auctions and matching markets, and community-based research in the nonprofit sector, and draw distinctions between what previous studies present and what we propose.

2.1. Resource Allocation and Procurement in the Nonprofit Sector

Nonprofit organizations acquire their resources through a combination of grants, donations, fundraising, cross-subsidization, pay for services, and related means; yet they face significant strategic challenges in procuring the assets necessary to support their beneficiaries (Berenguer and Shen 2020). There exist a few papers that use mathematical models to improve procurement in nonprofits, for example, game theoretic approaches that analyze a payment for results versus traditional funding schemes (Sharma et al. 2021). Similarly, Aflaki and Pedraza-Martinez (2023) use a game theoretic approach to explore three models that differ in competition: full and partial collaboration among humanitarian organizations and donors for disaster relief operations. An integer programming approach by Dalal (2022) guides which donors to engage from a set of potential donors and the flow of resources transferred to beneficiaries.

Once NPOs have procured resources, they need to determine their allocation to meet specific nonprofit needs, which is known as resource allocation. There exists a wide variety of optimization models for nonprofit resource allocation, focused on differing nonprofit resources, for example, volunteer management (Kaur et al. 2022, Berenguer et al. 2024, Escallon-Barrios et al. 2024), monetary fund allocation to nonprofit operations (Kotsi et al. 2022, 2023), allocation and management of resources to create promotional events (Ahire and Pekgün 2018, McKie and Ahire 2024), allocation of medical equipment (De Armas et al. 2021, Zhou and Olsen 2023), resource allocation in disaster relief operations (Blackmon et al. 2021), and allocation of limited education and family subsidies (Arora et al. 2021, Wei et al. 2024, Guda et al. 2024). Multiple recent review papers (Mahmoudi et al. 2022, Rivera et al. 2023, Esmaeilidouki et al. 2023) compile resource allocation models in the food bank sector.

A key difference between our work and the existing literature on resource allocation in the nonprofit sector is that in SWAP, offerings and requests originate from the same actors, whereas the majority of existing work considers the offering organizations (such as donors) and the receiving organizations (such as beneficiaries) as disjoint. Designing a system where NPOs both offer and request heterogeneous resources requires a careful design: incentivizing high-quality offers, establishing proper exchange languages, and implementing currency policies that facilitate scalable and efficient exchanges.

2.2. Market Design for Nonprofit Resource Exchange: Auctions, Matching, and Allocation

We review auction, matching, and exchange mechanisms relevant to the nonprofit settings, emphasizing designs deployed in practice (Kominers et al. 2017).

Our work is related to the market design literature on auctions and exchanges with virtual currency. Two major applications stand out. The first prominent application is "Course Match", an optimization tool implemented in several universities that allocates classes by processing student course preferences, budgets, and course targets and capacities to compute a clearing price for each course at an approximate competitive equilibrium from equal incomes (Budish et al. 2017). Another notable application is the "Choice System": an auction with virtual currency used by Feeding America to help distribute food donations across food banks in the United States and to reduce the time required to match donor resources (Prendergast 2017, 2022). Our work is also inspired by auctions and exchanges which use real money. One highly successful recent combinatorial exchange reallocates fish quotas in Australia. The design involves creating new bidding languages, demand and supply constraints, and solving quadratic optimization models by carefully considering seller statuses, institutional restrictions, and subsidy distribution (Bichler et al. 2019). The recent Federal Communications Commission "Incentive Auction" that reallocates and repackages spectrum from hundreds of TV stations to telecoms is another example of a very complex combinatorial exchange (Milgrom and Segal 2020). SWAP differs from these deployed mechanisms in three ways. First, SWAP uses virtual currency rather than real money. Second, SWAP is dynamic, as in the Choice System, and unlike Course Match. Third, SWAP is an exchange in which each NPO may participate on both the buyer and seller sides of the market, supplying resources and demanding others, which differs from assignment settings such as the Course Match and the Choice System, more closely resembling multi-party exchanges like the fishing quota and the Incentive Auction.

SWAP is also inspired by the literature on matching markets, where efficiency rather than pricing plays the dominant role (Roth 2015). A foundational model in this literature is the Shapley-Scarf housing market, which studies trading indivisible goods (such as houses) in a market where no money is exchanged (Shapley and Scarf 1974). They showed that the Top Trading Cycles (TTC) mechanism leads to a unique outcome in the core. This model has inspired several applications. The most prominent applications are donor-patient organ exchanges, in particular, kidney exchange (Roth et al. 2004, 2005, 2007). More recent work has explored tradeoffs that arise in dynamic kidney exchange; for example, exchanges must balance sufficiently frequent clearing to reduce patient attrition with the benefits of waiting for higher-quality matches (Ünver 2010, Akbarpour et al. 2020). In the realm of refugee resettlement, matching mechanisms are used to assign refugee families to communities in the designated country where they can resettle and start a new life toward eventual integration (Ahani et al. 2021, Delacrétaz et al. 2023, Ahani et al. 2024). For instance, Delacrétaz et al. (2023) introduce a framework that incorporates multidimensional family sizes and community capacities and applies TTC-like mechanisms that improve allocations of refugees using refugees' preferences. Unlike much of the literature in matching markets inspired by Shapley and Scarf (1974), we consider multilateral exchange using virtual currency rather than a TTC-like mechanism.

In the theoretical matching literature, multiple studies examine the relationship between market thickness and exchange efficiency. Two prominent works analyze the settings from homogeneous agents with symmetric mutual interests to heterogeneous agents, discussing the benefits and drawbacks of increasing market thickness and matching structure complexity when maximizing average waiting time exchange (Anderson et al. 2017, Ashlagi et al. 2019). Aouad and Saritaç (2022) show that the timing of matching decisions is critical for achieving efficient allocations in dynamic markets with stochastic agent arrivals and departures. Their results highlight a fundamental tradeoff between increasing market thickness and mitigating participant abandonment. Feng et al. (2024) propose batching strategies over a short time horizon improve matching and pricing decisions in two-sided stochastic matching problems arising in the gig economy. SWAP draws on similar central insights: that batching can increase market thickness, and multilateral rather than only bilateral matching can expand the feasible match set and improve match quality. In SWAP, however, batching is not only a response to stochastic arrivals and departures; it is also a way to aggregate heterogeneous haves and needs that NPOs identify in advance, creating sufficient thickness for optimization-based multilateral exchange.

From another exchange perspective, studying asset transfers in humanitarian supply chains, Bhattacharya et al. (2014) develop a stylized model comparing three designs: no transfers, direct bilateral transfers between aid programs, and transfers via a central intermediary. They show the efficiency of centralized systems in the context of matching and allocation. Ayer et al. (2019) propose a restless bandit model with a capacity-adjusted Whittle index policy to prioritize hepatitis C treatment in prisons under limited treatment capacity. Zhang et al. (2023) study inventory sharing for perishable products across two locations with stochastic demand and First In, First Out issuing, showing that transshipment decisions can be guided by the relative ages of the oldest inventory units at each location. These studies, like SWAP, address the allocation of scarce resources across competing needs. SWAP differs by embedding allocation in a reciprocal exchange market: NPOs seek resources from others while also offering resources of their own, and virtual currency helps express relative value across heterogeneous haves and needs.

Due to funding and resource challenges, NPOs have begun to design, experiment, and practice certain forms of collaboration to reduce competition for resources (Nonprofit Finance Fund 2025). Yet, research on NPO collaboration, its assessment, and mechanisms for its facilitation has seen less attention (Gazley and Guo 2020). Established techniques that match NPO haves to NPO needs remain scarce. We contribute a deployed, episodic exchange process through market design and integer optimization that supports resource exchange among NPOs.

2.3. Community-Based Research Approaches

Community engagement addresses social challenges and opportunities by involving stakeholders in solving community-specific problems. This participatory approach can complement the role of optimization in matching needs to alleviate resource scarcity among nonprofits, and we draw from multiple frameworks in our understanding of community-engaged research and design.

First is community-based participatory action research (CBPAR), wherein researcher teams, inclusive of community partners, influence the full research life cycle from problem identification to learning dissemination (Wallerstein and Duran 2006). This research methodology centers community voice and engages community stakeholders in a co-design process. Second is an asset-based community development (ABCD) lens, which, rather than a deficit lens, emphasizes the existing resources and opportunities from which communities can build in their pursuit of transformative goals (Mathie and Cunningham 2003, 2005). In the ABCD approach, community voice and human needs are integral in design processes towards a society where people collaborate for the greater good. Third is a democratic community engagement (DCE) approach that emphasizes the importance of community voice and provides a model for values of reciprocity, epistemic justice, and asset-based approaches to partnership (Saltmarsh et al. 2009). Fourth is community-based operations research (CBOR), which focuses on addressing public sector challenges by leveraging human resources and collective action to optimize outcomes for communities rather than stakeholders (Johnson and Smilowitz 2007). Fifth is collective impact, which focuses on cross-sector collaboration to achieve large-scale social change (Kania and Kramer 2011, Bouek 2018, Yang 2021).

Drawing on these frameworks, we have intentionally co-designed the following processes: 1) SWAP organizes communities around the technology; 2) SWAP is rooted in collective values that are articulated and aligned; and 3) SWAP's co-design process is conducted in a democratically engaged manner that attends to agency, voice, and full participation by nonprofit stakeholders.

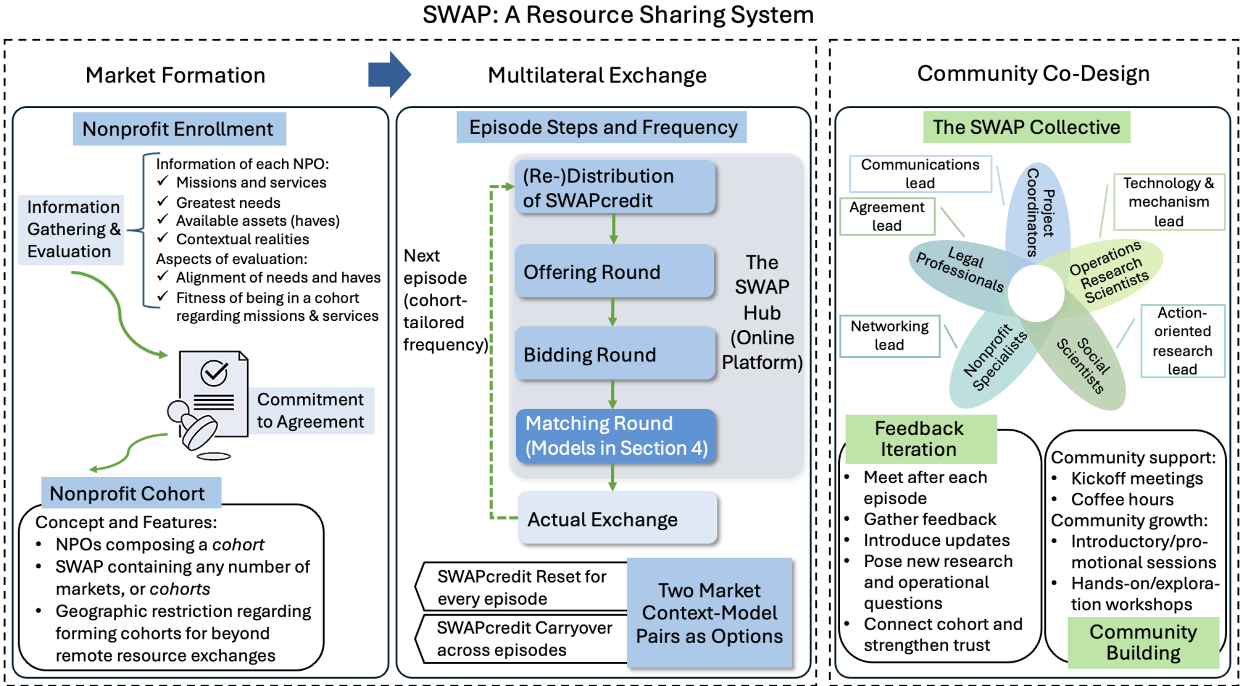
3. The SWAP System

The SWAP system is designed to meet three key objectives. The first is to establish markets that allow nonprofits to share their available resources to obtain needed resources. The second is to design the operational mechanisms to support resource exchanges, including developing straightforward offering and bidding methods for the auction-based multilateral exchange process, integer optimization models to determine efficient matching outcomes, and virtual SWAPcredit currency (re-)distribution policies to retain market balance. The third is to deploy SWAP in practice: to engage SWAP researchers, NPO professionals, and NPO stakeholders in an ongoing co-design process for continuous refinement and community adoption, arriving at a resource sharing system embraced by and actively benefiting nonprofits, and empowering both nonprofit collaboration and collective impact.

3.1. The SWAP System Overview

The SWAP system consists of three key components as overviewed in Figure 2. The market formation component describes the concept, features, and essential steps to form a *cohort*. The multilateral exchange component describes the steps or *rounds* of an *episode* that each cohort uses to exchange resources, facilitated

Figure 2: Diagram of the SWAP system depicting its three key components.



through an online platform, the *SWAP Hub*. The above two components together form a practical resource-sharing framework that has been successfully implemented to achieve numerous resource exchanges among NPOs (see Section 6). The third component is community co-design, which brings together participants to enhance the exchange experience and promote collaboration through communication, knowledge sharing, and community building. Community-based OR research, described in Section 2.3, recommends that optimization-based solutions be developed through a deeply collaborative development process. Accordingly, the design of each component incorporated regular feedback from NPO directors and staff, ensuring the system meets or exceeds their needs while securing critical stakeholder buy-in and trust.

3.2. Market Formation

In this section, we introduce the concept, rationale, and early-stage launching and scaling efforts of the SWAP resource sharing market, then describe how a cohort forms and is initially set up, how the self-governance agreement process functions, and how an NPO enrolls in an existing cohort.

3.2.1. SWAP Cohort The SWAP system can contain any number of instances of independent SWAP markets, or cohorts, each consisting of a group of resource-exchanging NPOs, where exchange processes, or episodes (see Section 3.3), are independently scheduled and conducted. Only NPOs in the same cohort may engage in mutual resource exchange. By design, we leave cohort size and composition to the discretion of the members; while cohorts with too few NPOs may have challenges in generating enough resources for meaningful matches, NPO participation ultimately depends on being willing to collaborate with one another. Thus, while cohort composition can vary, an ideal cohort would consist of NPOs that share needs-haves alignment and have existing or developing trusted relationships. A cohort may be a place-based group of NPOs in the same metropolitan area or commuting zone, as proximity is essential for exchanging physical resources. While cohorts can also form beyond geographical boundaries, in such cases, NPOs are limited to sharing remote talents, skills, subscriptions, and other intangible resources.

Launching and scaling a resource-sharing market requires deliberate, collaborative coordination in its early stages. Led by the SWAP collective, engagement of NPO participants was increased through three tactics: participatory stipends; modest early in-kind contributions from the SWAP collective, such as volunteering members' time and talents; and a transparent, simplified multilateral exchange process (including a credit-reset variant described in Section 4.5). These practices are reminiscent of established platforms' start-up strategies (e.g., Uber (Perera and Albinsson 2020) and Airbnb (Kessler 2013, Gallagher 2018)), and growth and scaling efforts (Varga et al. 2023, Chen et al. 2025).

3.2.2. Cohort Formation and Setup New cohorts form in multiple ways. One is through SWAP-oriented events that bring together independent NPO leaders interested in obtaining resources through sharing. Alternatively, a group of NPOs may have pre-existing networks and support infrastructure, which can lead to collective adoption. Once a group expresses interest in forming a cohort, the participating NPOs jointly decide on the types of resources to be exchanged, the timing and frequency of episodes, and then adopt or customize the Collaborative Agreement for Self Governance (CASG), thereby formalizing the cohort's governance. Every member of the newly formed cohort then completes the setup process, including signing the CASG and registering a SWAP Hub account.

3.2.3. Self-Governance Agreement The Collaborative Agreement for Self Governance (CASG) is a document adopted by each cohort that provides a shared understanding of collaboration and cooperation. As each NPO is both a buyer and seller of resources, the CASG highlights *reciprocal* relations as the basis of SWAP. The initial CASG was co-created by the SWAP collective and four NPOs in the inaugural cohort. Through that co-design, stakeholders negotiated a collaborative agreement to address liability and trust during resource mobilization. The resulting CASG covers participation, sharing, collective decision-making, and conflict resolution, and rests on three principles: (1) a collaborative spirit that prioritizes sharing resources; (2) a need for flexibility and understanding in achieving collective value; and (3) prioritizing staff safety and well-being by creating opt-in exchange opportunities for growth, learning, and networking that align with individual staff interests. The first principle reflects SWAP's core value—*commitment to community*. The second emerged from our early engagement with NPOs, which recognizes trust and understanding were critical in building a resilient cohort. The third principle recognizes initial skepticism among NPOs about data- and algorithm-driven platforms; accordingly, the CASG affirms SWAP's commitment to the informed consent, autonomy, safety, and well-being of individual workers.

3.2.4. NPO Enrollment in a Cohort New NPOs may be interested in joining and thereby expanding an existing cohort. Enrollment proceeds in two steps. First, background information is collected from the incoming NPO through several interactive activities: a short survey to identify mission, services, staff number, and resources of greatest need; asset mapping, a community tool to help realize existing resources within organizations; and networking meetups to understand organizational characteristics and context. This exchange of information allows existing cohort members to compare organization profile information, needs, and available resources, and to evaluate potential alignment. Given that SWAP relies on NPOs sharing resources with other NPOs, as well as the NPO sector's culture emphasis on transparency and autonomy, it is critical to respect the voices of existing NPO members in considering new entrants, and so based on these insights, the cohort determines by majority vote whether the NPO is fit to join. If accepted, the NPO signs the cohort's CASG and registers a SWAP Hub account, after which it may participate in subsequent episodes. Any NPO may also elect to leave a SWAP cohort; procedures are specified in the CASG.

3.3. Multilateral Exchange

The SWAP system conducts auction-based multilateral exchanges in discrete *episodes*, each consisting of five sequential rounds: SWAPcredit (re-)distribution, offering, bidding, matching, and actual exchange. Because NPOs do not know the full set of feasible exchanges ex ante, we first run an elicitation (offering) round to surface resources and give every NPO a shared view of the market. Offers are then frozen before bidding takes place, so that NPOs can evaluate all available resources. This design promotes equal opportunity for posting resources, as well as visibility into the full set of opportunities prior to commitment, reducing the risk of *intratemporal* exposure from early commitments that can arise when resources appear sequentially (Roth and Xing 1997, Avery et al. 2001, Roth et al. 2004). We note that the market design literature also highlights exposure that arises when participants value bundles yet can bid only on individual items (Goeree and Lindsay 2020). While combinatorial bidding languages can at least partially mitigate this phenomenon and are often attractive in high-stakes auctions with sophisticated bidders that can run over extended timelines, this might create missing bids and add excessive complexity for our setting, so we restrict bids to individual offers. By concentrating activity within an episode, rounds ensure a critical mass for meaningful multi-organizational exchanges and encourage participation (Roth 2018).

NPOs typically plan operations and services on regular cycles (e.g., seasonal, monthly, or weekly) and often know resource availability in advance; discrete episodes leverage this rhythm by allowing NPOs to prepare and coordinate resource offers more efficiently and with purpose, contrasting with continuous mechanisms (e.g., First In, First Out (Boomsma et al. 2014, Cantillon 2017)) that can fragment the market, impose heavy monitoring and preparation burdens, and lead to the exposure problem discussed above. As a co-designed system, the timing and frequency of episodes remain flexible and can be customized to each cohort's operational preferences and demand patterns (see Section 3.3.2).

3.3.1. (Re-)distribution of SWAPcredit SWAPcredit (for brevity, "credit" is used interchangeably) is a virtual currency within the SWAP system for capturing NPO preferences, or utilities. Credit may only be used for bidding on resources and holds no value outside of the SWAP system. Policies on the *initial distribution and redistribution* (or *(re-)distribution*) of credits are presented to cohort members before initial participation; greater detail on the policies and rationales under two market contexts is provided in Sections 4.2 and 4.4. In a newly formed cohort, the SWAP system allocates an amount of credits to each member as an initial endowment before the first episode starts. If a new member joins an existing cohort, they also receive an initial amount of credits upon joining. Thus, as the cohort size increases, the total amount of credits in the system also increases. If a cohort member leaves, an amount of credits equal to the member's initial endowment is deducted by removing the member's current balance and making use of redistribution policies to adjust for the differential between the initial endowment and the current balance. If no members join or leave, SWAP is a closed system, with no net increases or decreases in total system credit.

3.3.2. Episode Rounds and Frequency An *episode* comprises a sequence of activities as shown in Figure 2. In each episode, the credit balance for every NPO is set up by redistribution policies. At the start of the offering round, a representative of each participating NPO signs into the SWAP Hub (Section 3.3.5) to post available resources as *offers* (Section 3.3.3). The bidding round begins after the offering round closes, allowing participating NPOs to bid on desired resources that have been offered by other NPOs using credits as *bids* (Section 3.3.4). When the bidding round closes, all bids on all offered resources are known, and integer optimization (Section 4) is used to clear the market and determine the optimal matching. The results are then published in the SWAP Hub to communicate to NPOs what they are giving and receiving. Organizations obtaining resources initiate the exchanges, and such coordination occurs outside of the SWAP Hub, according to the rights and obligations of NPOs for giving and receiving resources as described in the CASG. Episodes are conducted sequentially. Each NPO can choose to opt out of any episode. While current practice suggests a bimonthly to quarterly episode length with offering and bidding rounds open for approximately one week and the remaining time to accommodate the actual exchanges, the length of each of these episodes can vary based on the desires of each cohort. Round lengths could become much shorter, such as the offering and bidding round, each being open for a half day on Friday, with the entirety of the subsequent week allocated to making actual exchanges.

3.3.3. Offering Round An *offer* consists of a resource name, an availability period, a short description of the resource, usage requirements, contact information, and an ask value in credits that represents the minimum utility the offering NPO is willing to accept. Nonprofits are free to make as many offers as desired, and the same resource can be posted as multiple offers with distinct time periods. For instance, a meeting room available on consecutive days (e.g., Thursday and Friday) can be posted as separate offers in the same round. Resources may also be time-flexible, meaning the resource can be used at any time within its availability period. For example, an NPO could offer 2 hours of MS Excel services, usable at any time in June. During an active offering round, NPOs have real-time access to all posted offers, including both their own and those of others.

The ask value of an offer is set by the posting NPO and reflects their assessment of the resource's utility during its associated availability period. The SWAP system only allows NPOs to bid on resources at levels that meet or exceed this ask value. This approach allows for flexible valuation and expression of diverse preferences, and avoids imposing uniform values on inherently heterogeneous resources. Even within a single resource category, such as grant writing assistance, value can differ significantly based on expertise, availability, and timing (i.e., may vary across episodes). Allowing offering NPOs to determine ask values encourages both purposeful engagement and context-sensitive valuation (Birge et al. 2024).

3.3.4. Bidding Round All bidding occurs under sealed bids. The sealed bid design protects against bid shielding and sniping that can occur in online auctions where the end of the bidding window is publicly known (Trevathan and Read 2006, Ely and Hossain 2009, Bose and Daripa 2017). With this format, each NPO submits a confidential bid without knowledge of the bids that other NPOs place, leveling the playing field and preventing such strategies. Sealed bidding is also simpler and faster than dynamic auctions, freeing NPO participants from continuously monitoring and updating bids.

We explore two distinct bidding contexts. In the first context, NPOs have the flexibility to bid on resources based on anticipated future earnings from successfully offering resources to others, allowing them to place bids that exceed their current balances (Section 4.3). The second market context restricts NPOs from placing bids that exceed their current balances. Unlike the first, this context allows incoming earnings to boost the value of placed bids (Section 4.5).

3.3.5. The SWAP Hub Each NPO in a cohort is provided with an account for the online *SWAP Hub* platform. A representative from each NPO signs in to their account to participate in any episode. Screenshots from the user's SWAP Hub perspective of What We Have (i.e., offering), What We Need (i.e., bidding), and Exchange Results are displayed in Appendix A. Based on NPO feedback, an additional featured tool, the *Chat Channel* is integrated into the SWAP Hub and accessible to all NPOs in the same cohort. The Chat Channel exists for NPOs between episodes to communicate their needed resource(s) for future episodes, which increases awareness of needs in the cohort in advance of the subsequent episode.

3.4. Community Co-Design

Through a process of community co-design, SWAP brings together expertise from multiple professional domains into a SWAP collective guided by principles of action research and community development (Swann 2002, Mathie and Cunningham 2003, 2005). The SWAP collective consists of operations research

(OR) scientists, social scientists, nonprofit specialists, legal professionals, and project coordinators, who together with NPO stakeholders co-design SWAP's processes, practices, and technology.

A key role of the SWAP collective is to engage with NPOs to raise awareness of the benefits of SWAP, support and incentivize cohort formation, and strengthen the broader SWAP community. Recruiting events invite NPO leaders from the same region to learn about SWAP and consider forming a cohort. Promotional sessions are conducted in-person and virtually, featuring SWAP overviews, introductory videos and demos, panel discussions, and interactive asset mapping activities. The asset mapping activity, combined with peer group discussions, helps NPOs identify and catalog underutilized assets within their organizations. This process highlights opportunities for collaboration and motivates NPOs to initiate resilient, empowered cohorts to leverage shared resources. SWAP workshops provide hands-on exploration of the resource-sharing process through mock offering, bidding, and matching exercises on the SWAP Hub.

NPOs contribute ideas to support and extend the community. Ongoing activities include kickoff meetings to launch new cohorts, events to improve exchange experiences, and informal gatherings like coffee hours to share and celebrate achievements. These efforts, supported by the SWAP collective, serve to build a community grounded in trust, engagement, cost-effectiveness, human welfare, accountability, and collective impact, values consistently endorsed by participating NPOs.

A *reflection session* is held after each episode to continuously refine the exchange process. These sessions encourage transparency by reviewing the episode, gathering participant feedback, introducing SWAP updates, and posing new research and operational questions concerning cohort-specific factors. A mixed-method approach is employed: qualitative evidence from observation, conversations, and surveys is used to contextualize and refine interpretations of quantitative data on participation and multilateral exchange. This process enables NPOs to review each episode and ensures that their experiences meaningfully inform system refinement. It also links iterative knowledge generation and ongoing community development.

Reflection sessions often reveal opportunities for SWAP design improvements and new research questions. For example, NPOs requested a way to track completion of resource exchanges; in response, a status table was added to the SWAP system. As the number of episodes grows, the SWAP collective and individual NPOs gain deeper insights into the human and social values that SWAP should support, leading to new research questions on value-driven technology development and refinement. Reflection sessions also help NPOs reach consensus on the scheduling of subsequent episodes, accounting for workloads, seasonal changes, and other cohort-specific considerations. Cohorts are encouraged to raise challenges and celebrate successes, which builds cohesion and strengthens relationships.

4. Mathematical Modeling

Each SWAP cohort can be considered as a one-to-one indivisible resource allocation (interchangeably, *matching*) market with each "match" generating a pair-specific surplus (Moulin and Sethuraman 2013, Hatfield et al. 2013). A distinctive feature of SWAP's design is that a participating NPO may be involved in some matches as a *buyer* and in other matches as a *seller*. Another key feature is that the resources offered may be heterogeneous and the participating nonprofits may have distinct preferences for these heterogeneous resources. We use integer optimization to formulate the matching problem and determine efficient multilateral exchanges once the offering and bidding information from a given episode within a cohort is complete. An allocation consisting of a set of matches seeks the maximum overall surplus, and such an allocation in our setting is Pareto-efficient: no participant can be made better off without making another participant worse off. Surplus comparisons are conducted using cardinal values that clearly and intuitively communicate the matching rationale to participating NPOs.

In this section, we first define key mathematical notation, and then introduce two market contexts with specific credit characteristics and (re-)distribution rules, followed by two corresponding integer optimization models.

4.1. Notation

We now introduce the necessary notation for our integer optimization models including sets, parameters, and decision variables.

4.1.1. Sets

- Let $\mathcal{N}$ be the set of NPOs in a cohort, indexed by i, j $(i \neq j)$
- Let $\mathcal{R}_i$ $(\mathcal{R}_j)$ be the set of resources offered by NPO i $(j) \in \mathcal{N}$, indexed by k (k')

4.1.2. Parameters

- c_i^0: Initial credit endowment of NPO $i \in \mathcal{N}$
- c_i: Credit balance of NPO $i \in \mathcal{N}$
- r_i^k: Ask value that NPO $i \in \mathcal{N}$ sets for offered resource $k \in \mathcal{R}_i$
- $b_{i,j}^k$: Bid value that NPO $j \in \mathcal{N}$ proposes for offered resource $k \in \mathcal{R}_i$ of NPO $i \in \mathcal{N}$

4.1.3. Decision Variables

- $x_{i,j}^k$: a binary variable; 1 if a resource $k \in \mathcal{R}_i$ of NPO $i \in \mathcal{N}$ is awarded to NPO $j \in \mathcal{N}$, and 0 otherwise.

4.2. Two SWAP Market Contexts

Nonprofit organizations vary in both their resource availability and demand over time, as well as their preferred approaches to managing credits. To accommodate this diversity and offer NPOs flexibility in how they participate, including their bidding manners and credit strategies, we design two market contexts: *credit carryover* and *credit reset*.

In the context of *credit carryover*, credit functions analogously to real currency, having value over time. This context allows credits to be stored and used in future episodes. SWAP must contend with an *intertemporal* exposure problem: an NPO may be unwilling to sell in one episode without confidence it can secure a needed resources in a future episode, a concern analogous to exposure risks in the kidney exchange systems (Roth et al. 2004). Allowing credits to carry over between episodes mitigates this exposure by letting NPOs bank value from current trades for future needs. Within this context, a match specifies a giving NPO, a receiving NPO, a provision of physical resources, skills, or subscriptions, and a credit transfer. Participants contribute their available resources to others in exchange for credits. The preferences of NPOs are captured by utility functions over sets of matches. Moreover, a strategic redistribution of credits (see Section 4.4) is designed to help NPOs who end up with too few credits to continue participating, while simultaneously preventing the formation of monopolies.

In the context of *credit reset*, at the beginning of each episode, the credit balance is reset to its original level for every NPO, that is, $c_i = c_i^0$ for all $i \in \mathcal{N}$. Credits cannot be stored for future use. Hence, only resources, and not credit savings, have utility, and in this setting, participants offer resources only to obtain immediate needs. In each episode, a rational participant will seek to exhaust their credit balance (e.g., 100 credits) by assigning bid values based on preferences over resources offered by others (e.g., 40 credits for an event space, and 60 for a minivan). The credit reset context serves as a practical baseline to explore core market design challenges and potential remedies in the NPO resource-sharing environment. It is grounded in well-known observations from market design with artificial currency, and deliberately avoids conditions where aggressive saving can lead to market failure, such as underspending (Sweeney and Sweeney 1977). By requiring balance exhaustion in each episode (effectively equivalent to infinite inflation), this context encourages trade and improves liquidity in the present episode, while also isolating participant behavior in the absence of forward-looking incentives, enabling clearer interpretation of preference expression and market dynamics in a static environment.

For both contexts, any initial credit endowment is possible. An identical amount of credits c^0 can be allocated if the participating NPOs are relatively homogeneous, that is, $c_i^0 = c^0$ for all $i \in \mathcal{N}$. Homogeneity can be assessed through self-reported information (e.g., staff number) as well as financial disclosures (e.g., highly compensated staff number, and annual gross in IRS Form 990). In the case of non-homogeneity, initial credit endowment levels can be established through consensus among the SWAP Collective and participating cohort members prior to the first episode.

4.3. Inflow-Outflow Balance Exchange Model with Credit Carryover

The inflow-outflow balance exchange model with credit carryover determines an optimal resource allocation by maximizing (1a), the total differential between placed bid values and ask values of exchanged resources, or named total surplus. The ask value for each resource, r_i^k, is set by the offering NPO i and reflects their personalized valuation, that is, a lower bound on how much they believe the resource is worth. Similarly, each bid, $b_{j,i}^{k'}$, submitted by NPO i for resource k' offered by NPO j, captures i's individualized perception of this resource's value. Thus, at any point in time, the objective function's goal to maximize total surplus captures the full complexity and heterogeneity of NPO preferences, and the total number of exchanges and hence achievable surplus is bounded above only by the volume of resources offered in the market.

Inflow-Outflow Balance Exchange (IOBE) Model.

$$\text{maximize} \quad \sum_{j\in\mathcal{N}}\sum_{i\in\mathcal{N}}\sum_{k\in\mathcal{R}_i}(b_{i,j}^k - r_i^k)x_{i,j}^k \tag{1a}$$

$$\text{subject to:} \quad \sum_{j\in\mathcal{N}} x_{i,j}^k \leq 1 \quad \forall i\in\mathcal{N},\ \forall k\in\mathcal{R}_i, \tag{1b}$$

$$\sum_{i\in\mathcal{N}}\sum_{k\in\mathcal{R}_i} b_{i,j}^k x_{i,j}^k \leq \sum_{i\in\mathcal{N}}\sum_{k'\in\mathcal{R}_j} b_{j,i}^{k'} x_{j,i}^{k'} + c_j \quad \forall j\in\mathcal{N}, \tag{1c}$$

$$x_{i,j}^k \in \{0,1\} \quad \forall i,j\in\mathcal{N},\ \forall k\in\mathcal{R}_i. \tag{1d}$$

The first set of constraints (1b) ensures that each offered resource is exchanged no more than once. The second set of constraints (1c) upholds the credit restriction that shapes how resources are awarded, thereby incentivizing the offering of resources. These constraints allow each NPO to be awarded any resource that they can afford—the credit balance c_j plus any incoming credits from offered resources that are exchanged, $\sum_{i\in\mathcal{N}}\sum_{k\in\mathcal{R}_j} b_{j,i}^k x_{j,i}^k$. The balance c_j serves the critical role of ensuring the possibility of exchanges. Without balances ($c_j = 0, \forall j\in\mathcal{N}$), no net credit gains or losses are possible for any participant. More broadly, constraint set (1c) plays a key role in promoting both the supply and demand sides to maintain sufficient market liquidity, supporting exchanges even in the absence of direct barter opportunities, and avoiding the "double coincidence of wants" problem that plagues traditional barter systems (Roth et al. 2007, Roth 2008). Each NPO can place as many bids as desired, earn credits by supplying desirable resources, and spend credits when needed, all without requiring perfectly bilaterally aligned needs. Moreover, the ability to earn credits by supplying high-value resources creates strong endogenous incentives for participation and supply-side liquidity. Concerning complexity, we prove that the Inflow-Outflow Balance Exchange model is strongly NP-hard in Appendix D.

4.4. Credit Redistribution in the Credit Carryover Context

In the credit carryover context, redistribution of credits takes place after the matching round in an episode according to pre-defined redistribution policies. Redistribution is facilitated through (a) the Community Collection (CC) that is funded through charges on matched resources and (b) the Maximum Individual Bound (MIB) that is designed to collect excessive stored credits so as to prevent monopolies. Credits collected by CC and MIB are used to assist NPOs whose post-match balances are below the Balance Lower Bound (BLB) ℓ (that is, imbalanced NPOs) in time of need. The BLB ℓ can be set to a value such as the average historical ask value to improve the likelihood that any NPO can afford at least one resource in the next episode. The CC charges receiving NPOs a small amount δ for each resource awarded, such as a fixed percentage or tiered rate based upon and added to the ask value. In this case, a bid value b meets or exceeds the ask value

r plus the small charge δ. These charges are integrated into the inflow-outflow balance exchange model by modifying constraint set (1c):

$$\sum_{i\in\mathcal{N}}\sum_{k\in\mathcal{R}_i} b_{i,j}^k x_{i,j}^k \leq \sum_{i\in\mathcal{N}}\sum_{k'\in\mathcal{R}_j}(b_{j,i}^{k'}-\delta_j^{k'})x_{j,i}^{k'}+c_j \quad \forall j\in\mathcal{N}, \tag{1c-alt}$$

where $\delta_j^{k'}$ represents a specific charge amount regarding resource k' offered by NPO j. The MIB, intended to cap the maximum credit accumulation, can be set to a pre-determined value u, such as the initial endowment per NPO c^0 plus a threshold based on the cohort size of NPOs. The redistribution amount to each imbalanced NPO can be determined by a cohort-approved, custom function $f(\cdot)$. One method is to raise all imbalanced NPOs' balances to the BLB; whereas a performance-based method could use the ratio of resources sent

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Algorithm 1 Redistribution of Credit in the Credit Carryover Context

Input: $\mathcal{N}$, episode t, $\{c_i^t\}_{i\in\mathcal{N}}$, $\{\mathcal{R}_i\}_{i\in\mathcal{N}}$, $\{r_i^k\}_{i\in\mathcal{N},k\in\mathcal{R}_i}$, $\{b_{i,j}^k\}_{i,j\in\mathcal{N},i\neq j,k\in\mathcal{R}_i}$, initial endowment c_i^0 for each NPO $i\in\mathcal{N}$, charges for community collection (CC) $\{\delta_i^k\}_{i\in\mathcal{N},k\in\mathcal{R}_i}$, maximum individual bound (MIB) u, and balance lower bound (BLB) ℓ

Output: Beginning balances for next episode $\{c_i^{t+1}\}_{i\in\mathcal{N}}$

1: Determine optimal $\{x_{i,j}^k\}_{i,j\in\mathcal{N},i\neq j,k\in\mathcal{R}_i}$ by solving the inflow-outflow balance exchange model
2: Initialize amount of collected credits $s=\max\{0,|\mathcal{N}|c_i^0-\sum_{i\in\mathcal{N}}c_i^t\}$ // Credits that may remain from the previous redistribution (see Line 17)
3: Compute $s=s+\sum_{i,j\in\mathcal{N},i\neq j}\sum_{k\in\mathcal{R}_i}\delta_i^k x_{i,j}^k$ // Credits collected based on CC
4: **for** $i\in\mathcal{N}$ **do**
5: $\quad c_i^t=c_i^t+\sum_{j\in\mathcal{N},j\neq i}\sum_{k\in\mathcal{R}_i}(b_{i,j}^k-\delta_i^k)x_{i,j}^k-\sum_{j\in\mathcal{N},j\neq i}\sum_{k'\in\mathcal{R}_j}b_{j,i}^{k'}x_{j,i}^{k'}$ // Post-match balance
6: $\quad$ **if** $c_i^t>u$ **then**
7: $\quad\quad s=s+c_i^t-u$ // Credits collected based on MIB
8: $\quad\quad c_i^t=u$
9: Initialize $s'=s$ representing the remaining collected credits after assisting imbalanced NPOs
10: **for** $i\in\mathcal{N}$ **do**
11: $\quad$ **if** $c_i^t<\ell$ **then**
12: $\quad\quad c_i^t=c_i^t+f(\cdot)$ // Credits given to imbalanced NPO i by custom function $f(\cdot)$
13: $\quad\quad s'=s'-f(\cdot)$
14: **for** $i\in\mathcal{N}$ **do**
15: $\quad c_i^{t+1}=c_i^t+s'\sum_{j\in\mathcal{N},j\neq i}\sum_{k'\in\mathcal{R}_j}\delta_j^{k'}x_{j,i}^{k'}/s$ // Unused collected credits returned to NPOs
16: $\quad$ **if** $c_i^{t+1}>u$ **then**
17: $\quad\quad c_i^{t+1}=u$ // No balance exceeding MIB; any remaining credits stored for the next episode
18: **return** $\{c_i^{t+1}\}_{i\in\mathcal{N}}$

---

to those received. Unused collected credits are returned to NPOs up to the MIB proportional to NPOs' CC contributions. A small number of collected credits may remain after the above process. The cohort determines in advance how to manage any remaining collected credits, for example, by distributing among NPOs that have not reached the MIB or retaining for redistribution in the next episode.

Algorithm 1 presents the computational procedure for the redistribution policies. As the credit balance incorporates redistribution for every episode, we augment the notation of balance c with a time period t in Algorithm 1 to indicate sequencing of episodes. The validation and case studies for the credit redistribution policies are presented in Section 5.2.

We recognize the possibility for an NPO to simply spend without offering resources at reasonable ask values, which may result in only obtaining resources and very low post-match balances, with the possible intent of being routinely rescued by redistribution. Three factors substantially mitigate this behavior. First, our co-design process includes reflection sessions with NPO leaders, allowing such patterns to be identified and appropriate actions taken. Second, redistribution provides limited returns to NPOs, discouraging excessive dependence. Third, we have found that NPO participants on the whole are less likely to engage in such behavior due to their altruistic missions and the collaborative culture fostered in the SWAP community.

4.5. Bid-Value Boost Exchange Model with Credit Reset

In the credit reset context, where a participant cannot store any earnings for future episodes, we introduce the bid-value boost exchange model, where any present earnings are directed toward increasing, or *boosting* the values of their placed bids, thereby increasing their likelihood of being awarded during the current episode. Specifically, bid value boosting increases the original value of each bid $b^k_{i,j}$ of participant j by the product of the ratio of the preference to the total allowable balance, $b^k_{i,j}/c^0$, and j's total earnings, $\sum_{k'\in\mathcal{R}_j}\sum_{i\in\mathcal{N}} b^{k'}_{j,i}x^{k'}_{j,i}$. This design is motivated by and based on observations that for NPOs, there is a nontrivial cognitive and coordination cost associated with identifying which resources to offer. It also draws on recent advances in market design using markup pricing for nonconvex economies, which represent a guaranteed subsidy for being willing to supply (Milgrom and Watt 2025). The bid-value boosting feature rewards NPOs that offer desirable resources at attractive ask values, which can increase market thickness and improve the likelihood of NPOs obtaining desired resources.

Bid-Value Boost Exchange (BVBE) Model.

$$\text{maximize} \quad \sum_{j\in\mathcal{N}}\sum_{i\in\mathcal{N}}\sum_{k\in\mathcal{R}_i}\left[\frac{b^k_{i,j}}{c^0}\left(\sum_{k'\in\mathcal{R}_j}\sum_{i'\in\mathcal{N}} b^{k'}_{j,i'}x^{k'}_{j,i'}\right)+b^k_{i,j}-r^k_i\right]x^k_{i,j} \tag{2a}$$

$$\text{subject to:} \quad \sum_{j\in\mathcal{N}} x^k_{i,j}\le 1 \quad \forall i\in\mathcal{N},\ \forall k\in\mathcal{R}_i, \tag{2b}$$

$$\sum_{i\in\mathcal{N}}\sum_{k\in\mathcal{R}_i} b^k_{i,j}x^k_{i,j}-\sum_{k'\in\mathcal{R}_j}\sum_{i\in\mathcal{N}} r^{k'}_j x^{k'}_{j,i}\ge 0 \quad \forall j\in\mathcal{N}, \tag{2c}$$

$$x^k_{i,j}\in\{0,1\} \quad \forall i,j\in\mathcal{N},\ \forall k\in\mathcal{R}_i. \tag{2d}$$

Objective function (2a) maximizes the total differential between boosted bid values and ask values over all exchanged resources. The product of binary variables in (2a) is linearized via a standard reformulation and variable substitution (Fortet 1960). The first set of constraints (2b) ensures that each indivisible resource is exchanged at most once. Constraint set (2c) ensures that the net utility for each participant is nonnegative, while (2d) expresses variable domains. A bidding rule enforced in the SWAP Hub is that participant j's total bid on resources must remain within their balance c^0. As rational participants, NPOs are likely to allocate most if not all of their credit balances when placing bids on resources, and in doing so scale their expressed preference values up to the balance, c^0.

5. Simulated Data Experiments and Results

This section presents three sets of experiments with simulated data to address three goals: (1) comparing the performance of the two SWAP market contexts and their corresponding models when NPO offering and bidding behavior is based on empirical data, (2) showing the benefits and market sustenance of credit redistribution in the inflow-outflow balance exchange model with credit carryover, and (3) demonstrating the computational efficiency of the two SWAP models on small to larger-scale markets.

The complete set of essential attributes simulated across all experiments is cohort size, initial balance, number of offers and number of bids for each participant, ask value for each offer, and bid value for each bid. In all of the experiments, each trial represents a unique combination of varied attributes, while controlling for the remaining factors. For each trial, 20 replicates are simulated, with each corresponding to a single SWAP episode. We conduct all experiments on a high-performance computing machine using Python version 3.12 and the PuLP library calling the CBC (COIN-OR Branch-and-Cut) solver (Forrest and Lougee-Heimer 2005), supported by an Intel(R) Xeon(R) CPU E5-2680 v4 @ 2.40GHz, reflecting setups on platforms similar to Amazon AWS and Microsoft Azure. Sections 5.1, 5.2, and 5.3 introduce the experimental settings for the three sets of experiments and present the findings concerning goals (1), (2), and (3), respectively.

5.1. Experiments on Performance Comparisons for the Two Market Settings

To compare the performance of our two multilateral exchange models with their corresponding market contexts, we simulate a 10-member cohort where NPO participant behaviors are guided by empirically-derived behavioral data obtained from the first 10 completed SWAP episodes from April 2023 to April 2025 in our Maryland inaugural cohort (see Section 6). The cohort members participate following the different participation probabilities: NPOs #1-4 participate in every episode, while NPOs #5 and #6, #7 and #8, and #9 and #10 participate in 75%, 50%, and 25% of the episodes, respectively. For each participant, we estimate the number of offers and the number of bids from observed empirical frequencies (see Table 1) and draw ask values and single bid surplus (i.e., bid less ask values associated with a given bid) samples from observed empirical distributions (Figure 3). For both contexts, each NPO's initial endowment is set at 100 credits per NPO. In the credit carryover context, the remaining credits of each participant from one episode serve as the starting balance for the next. Conversely, in the credit reset context, each participant starts each episode with a balance of 100 credits.

Attribute	Individual NPO Setting				
	NPO #1	NPOs #2, #3	NPO #4	NPOs #5-#10	
# of Offers†	$U\{3,5\}$	$U\{2,4\}$	$U\{1,3\}$	$B(5,0.5)$	
	NPO #1	NPO #2	NPO #3	NPO #4	NPOs #5-#10
# of Bids	Pr({1})=0.8 Pr({2})=0.2	Pr({1})=0.25 Pr({2})=0.75	Pr({1})=0.15 Pr({2})=0.425 Pr({3})=0.425	Pr({1})=0.5 Pr({2})=0.5	Pr({0,4,5})=0.3‡ Pr({1,2})=0.5 Pr({3})=0.2

†$U(l,u)$ represents a discrete uniform distribution between l and u; $B(n,p)$ represents a binomial distribution with n trials and probability of success p.

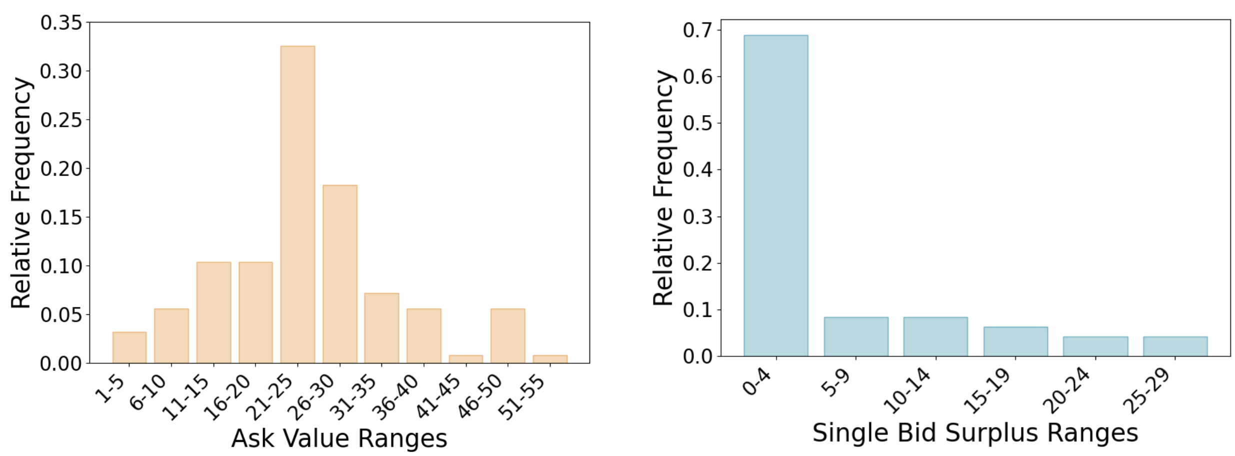
‡The probability that an NPO offers 0, 4, or 5 resources is equal (discrete uniform), and likewise for other discrete variables in each case.

Table 1: Individual NPO behavior distributions for numbers of offers and bids informed by empirical data.

Figure 3: Ask value and bid surplus distributions informed by empirical data.

(a) Ask value empirical distribution.

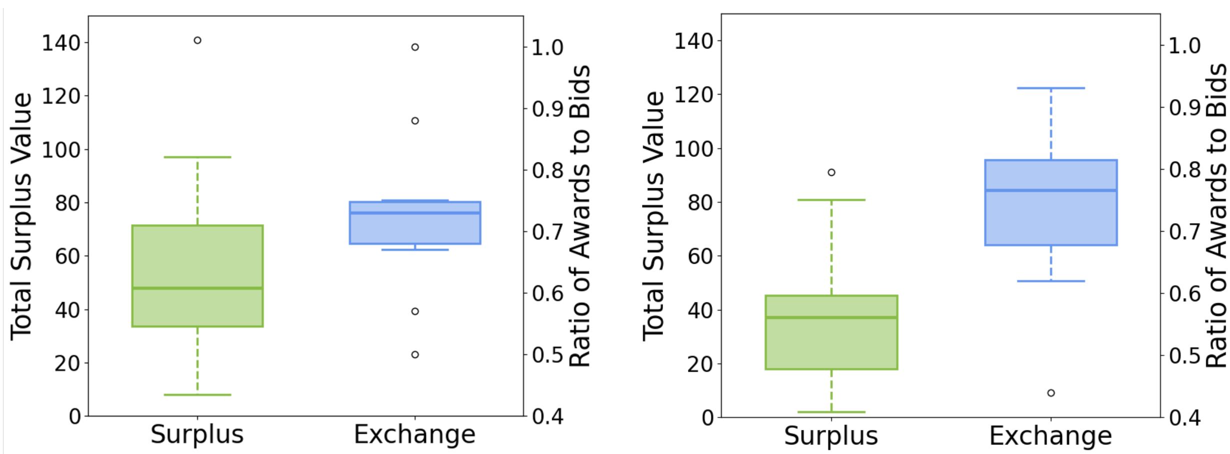
(b) Single bid surplus empirical distribution.



Figures 4a and 4b present episode performance from these experiments and show how the unique features of the inflow-outflow balance exchange (IOBE) and the bid-value boost exchange (BVBE) models, together with their market contexts, affect the exchange outcomes. We compare performance using two metrics: the objective value total surplus, and the ratio of awards to bids. The IOBE model yields a higher total surplus (median 48) than the BVBE Model (median 37) because, in IOBE, a participant's total bid value is not capped by balance, allowing a broader set of offer-need matches and greater aggregate surplus; in BVBE, total bids are restricted by the balance cap. By contrast, the BVBE model excels in bid fulfillment: by capping each participant's cumulative bids at the set balance, NPOs bid more selectively according to need, increasing the median awarded-to-placed bids ratio to 0.77. These distinct operating choices and performance profiles give cohorts options to select the market design that best aligns with their preferences.

Figure 4: Distributions of per episode surplus and exchange levels.

(a) Performance of IOBE Model. (b) Performance of BVBE Model.



Additional simulations exploring more aggressive offering and bidding behaviors are reported in Appendix B and an earlier study (Huang et al. 2023). A key reflection from these experiments is that, regardless of the chosen market option, it is essential to raise awareness of the temporal availability of resources. This can be done, for example, by encouraging NPOs to embrace asset mapping (see Section 3.4).

5.2. Experiments on Credit Redistribution Policies in Supporting SWAP Market

The credit redistribution experiments illustrate how the redistribution policies assist NPOs to continue participating when their remaining credits fall below a Balance Lower Bound (BLB) level, which in our experiments is set to 40 and prevents monopolies by setting proper Maximum Individual Balance (MIB). As described in Table 2, the experiments vary the following factors: Community Collection (CC) with low, light levels (L1) to high, restrictive levels (L3) as per the formula $\delta = \lceil \lambda r \rceil$ and tiered λ rates; Maximum Individual Balance (MIB) ranging from low (L1) to high (L3); and beginning balance interval (BBI) from narrow (L1) to wide (L3). A total of $3^3 = 27$ runs are tested across three levels (thin (L1) to thick (L3)) of market thickness (MT) which consists of offers and bids both from low (L1) to high (L3) (see the last two rows in Table 2). The controlled attributes remaining in the fixed setting appear in Table 3.

We begin by exploring the combinations of market thickness (MT) and beginning balance interval (BBI) that influence the number of NPOs (right y-axis with yellow points) with low post-match balances and the

Varied Factor	Levels: L1, L2, and L3		
	Low (L1)	Medium (L2)	High (L3)
Community Collection (CC)	$\lceil 0.03r \rceil$ for $r \in [1,15]$ $\lceil 0.05r \rceil$ for $r \in [16,30]$ $\lceil 0.07r \rceil$ for $r \in [31,45]$ $\lceil 0.09r \rceil$ for $r \in [46,75]$	$\lceil 0.07r \rceil$ for $r \in [1,15]$ $\lceil 0.09r \rceil$ for $r \in [16,30]$ $\lceil 0.11r \rceil$ for $r \in [31,45]$ $\lceil 0.13r \rceil$ for $r \in [46,75]$	$\lceil 0.12r \rceil$ for $r \in [1,15]$ $\lceil 0.14r \rceil$ for $r \in [16,30]$ $\lceil 0.16r \rceil$ for $r \in [31,45]$ $\lceil 0.18r \rceil$ for $r \in [46,75]$
	Low (L1)	Medium (L2)	High (L3)
Maximum Individual Bound (MIB)	150	200	250
	Narrow (L1)	Medium (L2)	Wide (L3)
Episode Beginning Balance Interval (BBI)	$U(90,110)$	$U(60,140)$	$U(30,170)$
	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($\{R-1,...,R+2\}$)=1	Pr($\{R-1,...,R+2\}$)=0.5 Pr($\{R+3,...,2R\}$)=0.5	Pr($\{R+3,...,2R\}$)=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.

Table 2: Varied factors and levels for credit redistribution.

Controlled Attribute	Setting		
Number of NPOs	10		
Ask Value	Pr($X \in \{10,...,24\}$)=0.6	Pr($X \in \{25,...,39\}$)=0.4	
Bid Value†	Pr($X \in [1.0r,1.3r]$)=0.3	Pr($X \in [1.3r,1.6r]$)=0.4	Pr($X \in [1.6r,1.9r]$)=0.3

†Let r denote the ask value of the corresponding offered resource, which is always integer-valued.

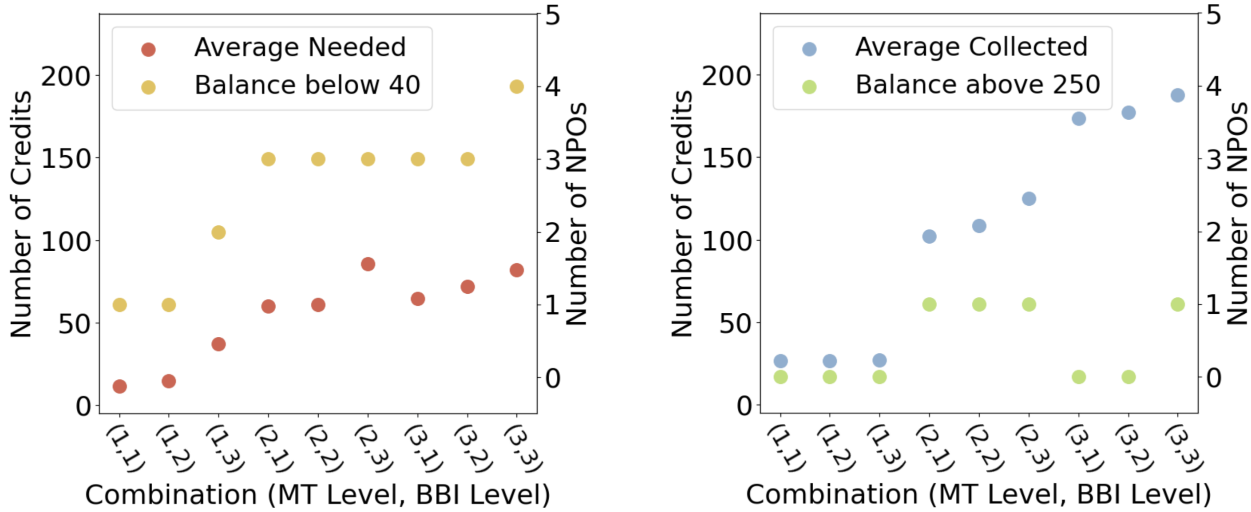
Table 3: Settings for controlled attributes for credit redistribution experiments.

total number of credits needed on average (left y-axis with red points) for their support (Figure 5a). For a given MT level, a wider BBI increases the likelihood of NPOs falling below the balance lower bound (BLB) of 40 credits. And for a given BBI level, among the three MT levels, thicker markets tend to have more NPOs with balances below 40 credits, as indicated by the trend of the yellow points in Figure 5a. The total number of credits needed also increases with market thickness: in thick markets, averages range from 64.5 to 82.1 (the last three red points in Figure 5a), while in thin markets, they range from 11.9 to 37.0 (the first three red points in Figure 5a).

We next analyze the number of NPOs with their balances over MIB (right y-axis with green points), and the total collected credits on average (left y-axis with blue points) which are the sum of credits collected

Figure 5: Credit distribution policy review.

(a) Needed credits. (b) Collected credits.



through MIB and CC as shown in Figure 5b. This Figure is based on the most conservative situation, where CC is low (L1) and MIB is high (L3). The number of NPOs with their balances over MIB maintains low at either 0 or 1 NPO throughout. Thicker markets always have larger numbers of the total collected credits compared to thinner markets (e.g., MT L3 compared to L2).

Finally, we investigate the ability of the market to self-sustain across all 27 MIB-BBI-CC combinations and three levels of MT. In thick markets (MT as L3), for each combination and each replicate, the total collected credits are always larger than the total needed credits, revealing that self-sustenance arises only under the widest BBI and highest MIB, with 3 out of 20 replicates failing for CC as L1, while 1 out of 20 fail for CC as L2. In markets with medium thickness (MT as L2), the challenge of self-sustaining arises only under the widest BBI and highest MIB, with 3 out of 20 replicates failing for CC as L1, and 1 out of 20 replicates failing for CC as L2. Among thin markets (MT as L1), only 3 out of 27 combinations are self-sustaining across all 20 replicates, but for all instances in which the market fails to self-sustain, the shortfall in collected credits is minimal. Either lowering MIB to L1 or increasing CC to L2 or L3 resolves these issues for thin markets. Thus, the credit redistribution policies function as intended, providing necessary support and regulation for NPOs so that the markets have the ability to sustain themselves. Additional details of credit redistribution performance in two concrete markets are reported in Appendix C.

5.3. Experiments on Computational Efficiency

In this section, we evaluate the run time performance and scalability of our proposed two models. To do so, we examine the 7 levels of the number of NPOs, ranging from 5 (L1) NPOs to 100 (L7) NPOs, while keep all the other attributes in a fixed setting as detailed in Table 4.

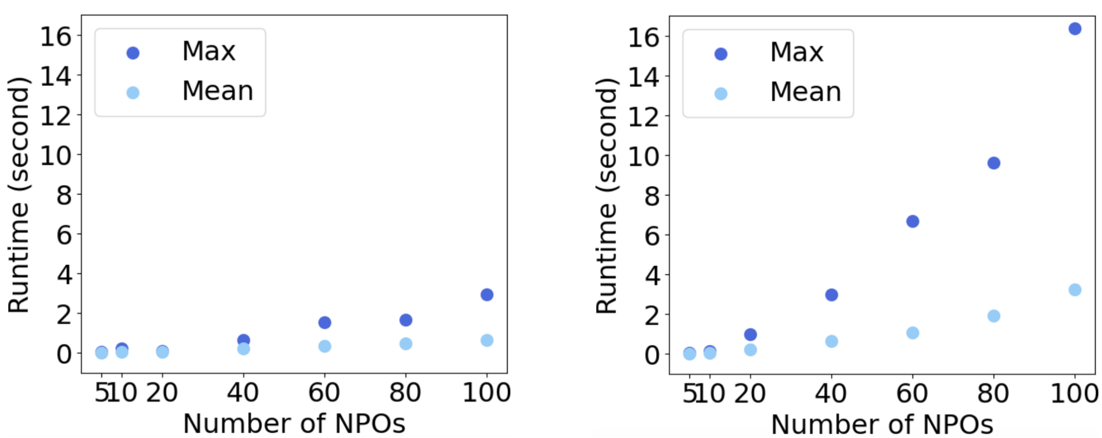
Varied Factor	Levels: L1, L2, ..., L7		
# of NPOs	5, 10, 20, 40, 60, 80, 100		
Controlled Attribute	**Setting**		
Initial Endowment	100 credits per NPO		
# of Offers per NPO	Pr($X \in \{0,1,9,10\}$)=0.2	Pr($X \in \{2,8\}$)=0.15	Pr($X \in \{3,...,7\}$)=0.65
Ask Value	Pr($X \in \{10,...,24\}$)=0.6	Pr($X \in \{25,...,39\}$)=0.4	
# of Bids per NPO	Pr($X \in \{R$-1,...,R+2$\}$)=0.5	Pr($X \in \{R$+3,...,2$R\}$)=0.5	
Bid Value	Pr($X \in$[1.0r,1.3r])=0.3	Pr($X \in$[1.3r,1.6r])=0.4	Pr($X \in$[1.6r,1.9r])=0.3

Table 4: Parameter settings for computational efficiency experiments.

Figures 6a and 6b illustrate the mean and maximum run time in seconds at each cohort size level. As the number of NPOs increases from 5 to 100, the average run time for the inflow-outflow balance exchange model (IOBE Model) ranges from 0.02 to 0.63 seconds, while the average run time for the bid-value boost exchange model (BVBE Model) ranges from 0.02 to 3.24 seconds.

Figure 6: Run time across seven cohort sizes.

(a) Run time for IOBE Model. (b) Run time for BVBE Model.



The observed increase in run time results from the added complexity of matching as the number of participants offering and bidding on resources grows. The quadratic objective of the BVBE Model is linearized through a transformation (Fortet 1960) prior to solving with the CBC solver (Forrest and Lougee-Heimer 2005), leading to a slight increase in run time. The run time distributions in Figures 6a and 6b indicate that the SWAP models can be solved efficiently across a wide range of cohort sizes, from small to very large, with even the longest solving to optimality in well under one minute (17 seconds).

6. From Idea to Impact: Nonprofits Using SWAP in the Real World

We next offer observations and insights drawn from our analyses of NPOs employing SWAP in real-world settings. In Section 6.1, we present empirical findings from SWAP workshops attended by NPO leaders, where results indicate strong alignment between NPOs' expressed needs and what other NPOs are willing to offer, and a substantial interest from nonprofit leaders in converting these needs-haves alignments into actual resource exchanges through SWAP. In Section 6.2 we provide data from the deployment of SWAP via a controlled pilot to two cohorts of NPOs, which offers evidence that SWAP can serve as a new method for obtaining resources NPOs need to meet their organization's needs and evidence that NPOs are willing to share need-aligned resources via SWAP. Finally, in Section 6.3 we present qualitative learning from the iterative feedback process.

6.1. NPO Demand for Resource Sharing Markets: Latent, Emerging, and Sustainable

Two half-day SWAP workshops were held in Baltimore, Maryland, on February 16, 2024 (in-person) and March 22, 2024 (online). Both featured identical participatory activities, with all attendees completing pre- and post-event surveys. Across the two workshops, 15 leaders from 10 different NPOs participated.

The first series of activities enabled a two-fold exploration: discovering resource needs experienced by each NPO, and revealing to NPOs how many of their assets can benefit other NPOs significantly. Figure 7a summarizes the 77 reported needed resources, categorized using a modified asset mapping framework (Mathie and Cunningham 2003). The greatest demand was for *Skills* (55.8%), primarily including *Creations* (30.2%) and *Trainings* (23.3%). Other significant demands were for *Connections* (18.2%) and *Physical Assets* (14.3%). In a subsequent asset mapping activity, participants listed resources they could offer to others. Figure 7b displays the 65 reported resources, segmented by the same classification schema. Comparing with Figure 7a, the asset mapping categories of the offered resources in Figure 7b coincide with all of the needed resource categories, differing only in percentages. These observations indicate strong alignment between needs and available offerings across the participating NPOs. Participants emphasized that the

Figure 7: Comparison between needed resources and offered resources in asset mapping categories.

(a) Distribution of potential needed resources. (b) Distribution of potential offered resources.

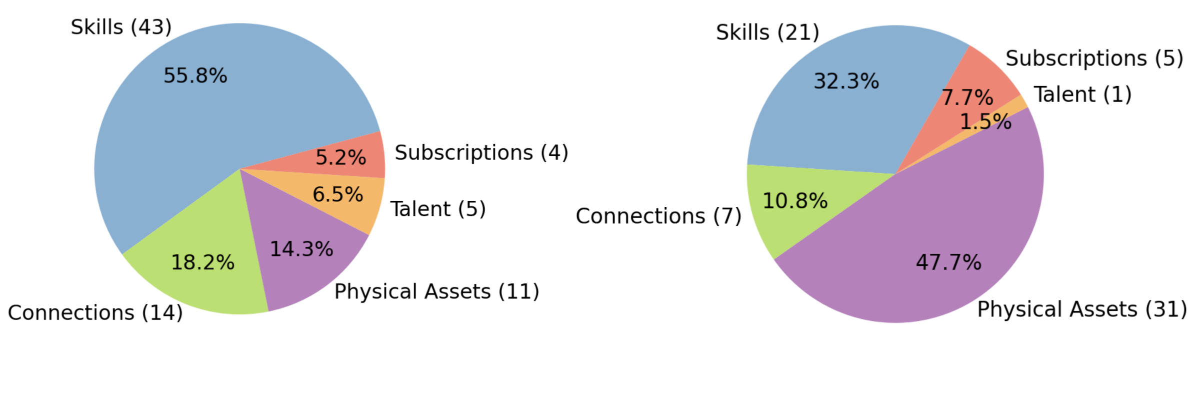
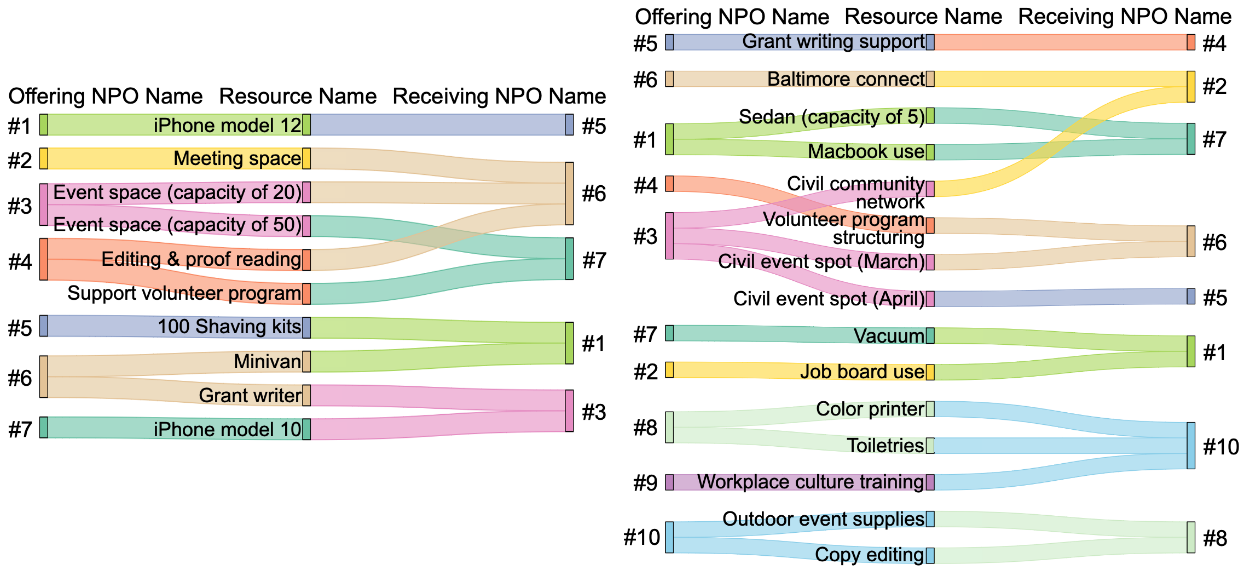


Figure 8: Instance of sustainable and diverse resource exchanges varying seasons.

(a) Resource exchanges in winter among seven NPOs.

(b) Resource exchanges in spring among the same seven NPOs plus three new NPOs.



activity surfaced previously unrecognized exchange opportunities. One NPO conveyed, "I thought it was very useful to have this activity because I would have not come up with something like grant writing that could help other peer NPOs without it." Others noted that the exercise allowed them to "learn together" and develop a sense that they could depend upon one another. This sentiment was shared by other participants, demonstrating that the asset mapping exercise led to more appreciation for one's organizational strengths and gifts, as well as increased assurance that resource exchanges would be of mutual benefit and support.

The next series of activities had NPO directors identify underutilized assets to offer and temporal needs to bid on based on their seasonal activities. Figure 8a and 8b illustrate resulting offer-need matches, where each color represents a unique NPO and their offerings are shown at left and their receivings are shown at right. Considering a winter season, 10 resources were matched among 7 NPOs (Figure 8a); and 15 resources were matched among 10 NPOs across two activity groups for a spring season (Figure 8b). All but one participating NPO received at least one, and most NPOs were matched with two to three needed resources. These findings illustrate the opportunity for diverse demands to be met through resource exchange as seasons vary.

Pre- and post-surveys were administered to evaluate NPO leaders' perception and perspective shifts regarding barriers and opportunities of exchanging resources and joining in SWAP before and after our workshop. Alongside the aforementioned hands-on activities, the concepts, components (shown in Figure 2), and principles of SWAP were explained with examples, demos, and interactive Q&A sessions. Survey results show that SWAP was perceived to effectively eliminate or mitigate four barriers to greater resource sharing identified by NPO leaders prior to the workshop. These barriers were limited visibility into what resources are available from other nonprofits; a lack of a fair and easy way to match needs and available resources in our nonprofit community; a lack of a practical way to coordinate the exchanges of shared resources in our nonprofit community; and risks with talent and skill resource sharing, for example, privacy, staff safety, and staff turnover concerns. Immediately following the workshop, 14 of 15 NPOs report a strong interest in joining SWAP, with 8 of the 14 indicating intentions to enroll soon. These findings demonstrates that NPOs recognize both the benefit for their individual organizations and the collective impact within the nonprofit community of resource sharing, and view SWAP as a practical and impactful solution for facilitating resource sharing.

6.2. Establishing and Growing SWAP Cohorts: Descriptors and Trends

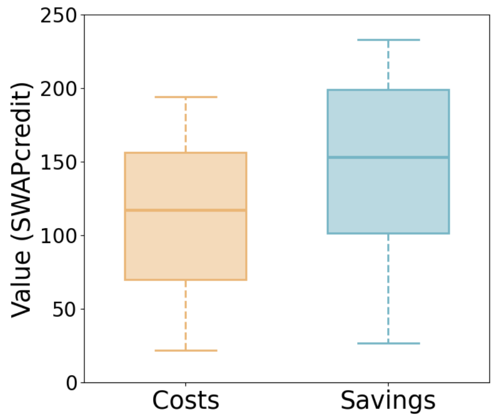
Data in this section come from the deployment of SWAP with two cohorts. As described in the previous sections, cohorts are able to personalize many SWAP features. About the episode cadence, the inaugural cohort preferred to have longer offering and bidding rounds along with one month actual exchange period, while the second cohort chose shorter offering and bidding slots with a season long exchange window. A workshop survey showed preferences for the two market contexts were evenly split; while in practice, both cohorts chose the credit carryover context, as they considered that during an NPO's lighter workload periods, they can contribute more and save credits for future busy periods' needs.

Since its inception in April 2023, the inaugural SWAP cohort in Howard County, Maryland, has operated continuously and completed 11 episodes by August 2025. Cohort data reveal that exchanges help NPOs to meet their own needs while also demonstrating that NPOs are consistently willing to offer resources to fulfill the needs of others. Measured in SWAPcredits, the saved value (i.e., total bid value of exchanged resources) per episode ranges from 27 to 233 and in total generates $1,571$ (see the right boxplot in Figure 9a). In every episode, savings exceed associated costs (i.e., total ask value of exchanged resources showed as the left boxplot in Figure 9a), underscoring benefits to member NPOs. Exchanged resources span diverse categories such as copying services, graphic design, marketing space in weekly emails, MS Excel training, meeting spaces, video editing services, and marketing and operations consultations. Critically, these resource exchanges enable NPOs to complete activities of importance to their organizational mission previously out of reach due to resource limitations. An NPO leader illustrates the impact in an email to the SWAP collective: *Through one of our SWAP partners, we're making a mission video, which is something that we've wanted to do for a long time.*

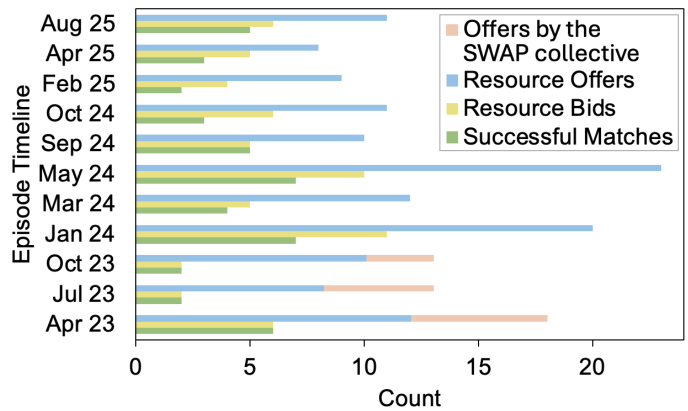
The research team voluntarily offered remote skills resources during the first three episodes to incentivize participation. As the inaugural cohort grew and members identified their own shareable resources, these contributions were phased out after the third episode. Figure 9b reports activity across the 11 episodes: on average, there were 13.5 resource offers, 5.6 bids, and 4.2 successful exchanges per episode.

Figure 9: Episode data visualization for the inaugural cohort.

(a) Distribution of cost and saved values of exchanged resources per episode.



(b) Distribution of offers, bids, and exchanges for each episode.



This cohort expanded from an initial four NPOs to seven members. The missions of these NPOs span a wide variety of domains, including housing, financial, workforce, education, parenting, mental health, transportation, and beyond. Across episodes, at least four and as many as seven NPOs actively offered or bid on resources. Cohort participation can depend on various factors, and we have observed NPOs impacted by family well-being issues and peak work periods, which can cause suspensions in activity. Cohort members have also recommended other nonprofits to join SWAP, serving as a key source of recruitment. These grassroots efforts highlight the value NPOs find in SWAP and facilitate organic cohort growth. Data from this inaugural cohort illustrates the appeal of SWAP to NPOs as a means for exchanging resources and confirms their ongoing commitment to sharing. The cohort's sustained growth and participation over time point to its increasing strength and resilience.

The second cohort based in Southwest Baltimore, Maryland, initially formed right after a SWAP workshop with four core NPOs. An additional NPO later joined after a special invitation to organizations by the networks of existing members. These NPOs represent diverse domains, including volunteering, tool and equipment support, environmental sustainability, and veteran assistance. Their first episode, launched in March 2024, featured 26 resources offered, 9 bids placed, and 9 resources exchanged, yielding 24 surplus value in SWAPcredits. After that episode, one member representative remarked, *"We would have never known that they could use these whiteboards that we have sitting in our warehouse, or the paint, so it was a really great opportunity,"* highlighting two successful exchanges. The next three episodes, completed over the following year, included 47 offers, 20 bids, and 19 resource exchanges. The surpluses were 30, 20, and 26, respectively, with total costs of 288 and savings of 364 SWAPcredits. This second cohort demonstrates that interest exists for the SWAP concept and that its design can be replicated for additional NPO cohorts. Incorporating lessons from the first into the second cohort accelerated their onboarding process, illustrating

Theme	Example Quote from Cohort Members
Mutuality and Responsibility	"*I love… the accountability and structure and how it builds community.*"
Appreciative Inquiry and Assets	"*I thought it was very useful to have the practice session because some of this is conceptually more animated because we had that [session] and I think I would not have come up with something like grant writing had we not had the practice session.*"
Temporality	"*You know, for us at the [organization name], I might look at something radically different in November when I feel like we can store things in our warehouse than I would in July when I want to get rid of it.*"
Thought Partnership	"*For planning purposes, I feel like we need less tangible stuff, right? And more like service and thought partnership support. Because when we have a physical, tangible need, it usually is like in the moment, right?*"
Building Collective Impact	"*This changes how we work and how we can collaborate more with others.*"
Leveraging for further resources	"*We mention being part of SWAP as a demonstration of community collaboration on grant applications for [organization name] SWAP builds relationships.*"

Table 5: Feedback from cohort members, organized by theme.

the power and impact of the co-design process. In summary, these results illustrate that SWAP appeals to a wide variety of NPOs as a new method for obtaining the resources needed for their missions and services and that NPOs are willing to offer resources of their own that satisfy the needs of other cohort members.

6.3. Qualitative Insights from Iterative Feedback Process

SWAP's design emerged through co-design and embraced an iterative feedback process that combined quantitative methods from operations research with community-based qualitative approaches. Grounded theory analysis of the reflection session transcripts identified key themes informing system development: mutuality and responsibility; appreciative inquiry and asset definition; the temporal cadence of exchanges, thoughtful partnership within cohorts; the capacity to collaborate for collective impact on shared goals; and leveraging participation in SWAP for additional resources and support. Table 5 summarizes these themes and presents illustrative quotes.

Key lessons learned from this process highlight how SWAP's co-design process, grounded in *convergence research* and transcending disciplinary boundaries (Roco 2016), can address the interplay of the technical and social that forms SWAP. This approach enabled systematic inquiry into questions, such as: *Should SWAP be framed as a community tool? How should we handle ownership of the algorithm? How do technical methods like mathematical modeling complement social procedures such as community agreements?* The iterative development of SWAP was guided by reflecting on such questions and using multiple forms of information—scientific, practical, and governance-related (Schikowitz 2020). For instance, the mathematical modeling of SWAP as an auction market operationalized the social concept that exchanges require mutual responsibility, and mutual responsibility was also a central concept of SWAP's Collaborative Agreement for Self-Governance (Section 3.2.3). This illustrates how quantitative modeling can be linked with governance design. Such an approach can also identify and address early concerns. For example, based on concerns about time, capacity, and the adequacy of contributions from partner NPOs, new technical tools and SWAP events were introduced, including the Chat Channel and asset mapping exercises. These build a community grounded in shared values and mutual support. Finally, a key lesson is the importance of collaboration and reflection in achieving sustainable co-design outcomes. Through regular team meetings and periodic cohort check-ins, iterative and continuous improvement of SWAP is further institutionalized.

Overall, findings demonstrate that the co-design process, embracing iterative feedback and a convergent research approach, can lead to a SWAP design that can increase collective impact through a combined technical and social developmental process.

7. Conclusion

While resource sharing among NPOs offers an opportunity to amplify collective impact, it requires greater transparency into resource availability and needs, along with efficient mechanisms to enable exchange. In response, we propose SWAP (*Sharing With A Purpose*), a novel resource sharing system that enables NPOs to obtain available resources from other NPOs while sharing their own. The SWAP system consists of three key components: market formation, multilateral exchange, and community co-design. Market formation collects NPOs into cohorts for resource exchange and sets forth the rationale, rules, and legal guidelines that govern how they share resources. The multilateral exchange features two auction-based exchange market contexts where balances of *SWAPcredit*, a virtual currency, are updated before a series of offering, bidding, matching, and actual exchange rounds, with integer optimization guiding the exchange process. The online *SWAP Hub* platform allows NPOs to seamlessly manage offers, bids, and exchanges. Through community co-design, the SWAP collective and NPO members work together to refine the system, promoting trust and building a stronger sense of community.

Simulated experiments reveal distinct matching outcomes for the two models under their respective market contexts and under empirically informed participation, offering, and bidding behaviors. The results also confirm the computational efficiency of SWAP, even in larger-scale markets, and highlight the effectiveness and benefits of credit redistribution in the credit carryover context. Setting appropriate maximum individual bound and community collection levels discourages market dominance, assists NPOs with extremely low balances, and helps maintain healthy competition across markets of varying levels of thickness.

Real-world data collected from workshops, over 70 completed resource exchanges in two Maryland-based cohorts, and feedback received from reflection meetings demonstrate that SWAP improves resource acquisition for participating nonprofits. The exchanged resources have fulfilled a range of NPO activities that include marketing, fundraising, and service provision. Through frequent, active interactions, NPOs have recognized the value of thought partnership, enhanced collaboration, and deeper relationships within the SWAP community.

SWAP transitioning from the controlled pilot toward broader implementation provides a foundation for future research. While this study focused on small to medium-sized NPOs, there is an opportunity to broaden the scope to include organizations of varying scales and imbalances of needs. These diversities may manifest and reshape how we elicit preferences, define credit (re-)distribution, and determine match results. Moreover, as markets thicken, it will be valuable to investigate the extent to which certain resources are complementary for participants. In the presence of such complementary resources, a natural and impactful direction is to enable bundle bidding and contingent trades. A further promising direction is to augment NPO-to-NPO exchanges with skilled volunteers from for-profit organizations, especially as corporate social responsibility and paid volunteering programs expand (Matten and Moon 2004, Lindgreen and Swaen 2010, Knox 2020). Extending SWAP to accommodate such external offers raises design questions (such as how should such offers be both *represented* and *allocated* within episodes). A final direction is to study how SWAP design choices interact. Their joint effects on participation, retention, and market dynamics remain underexplored, and systematic analysis could identify complementarities and tradeoffs that inform multilateral exchange systems more broadly.

Nonprofits increasingly need new ways to obtain resources beyond grants and donations. SWAP points toward a future where NPOs meet more of these needs through collaborative exchange, generating greater value from available and underutilized resources.

Acknowledgments

We gratefully acknowledge support of the National Science Foundation (FW-HTF 2222713, FW-HTF 2222697, and CIVIC-PG 2431414). We thank Mike Mitchell for conceptualizing SWAP and championing nonprofits; Rita Hamlet and Kristopher Madore for coordination and legal support; Elise Deshusses for early-stage experiment design and execution; Özge Aygül, Utku Yakar, and Aditya Madabhushi for refining the SWAP Hub; and PJ Sawchuk and Christina Bauer for operational support. We are grateful to Oleg Prokopyev, Faidra Monachou, and Vahideh Manshadi for insightful discussions that have improved the manuscript. We also thank the T. Rowe Price Foundation, Barbara Shapiro, Paul Wolman, and the France-Merrick Foundation for initial funding of the SWAP Hub. Finally, We sincerely thank the Association of Community Services, Baltimore Community ToolBank, Baltimore Tree Trust, Break a Difference, Bridges to Housing Stability, Columbia Housing Center, Evolving Minds, Glass Soldier, Luminus, MakingChange, Maryland Works, Neighbor Ride, Reveille Grounds, Science is Elemental, ShareBaby and numerous other nonprofits for their partnership in organizing events and participating in SWAP episodes. Their collaboration made this research possible.

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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.

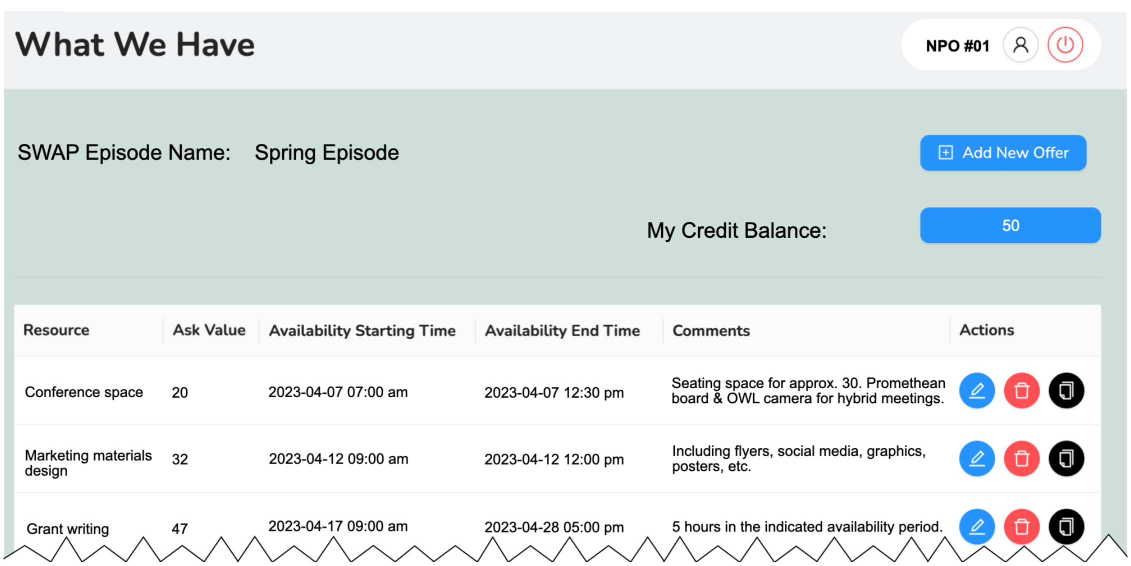


Figure 11: The “What We Need” view in SWAP allows NPOs to bid on resources during the bidding round.

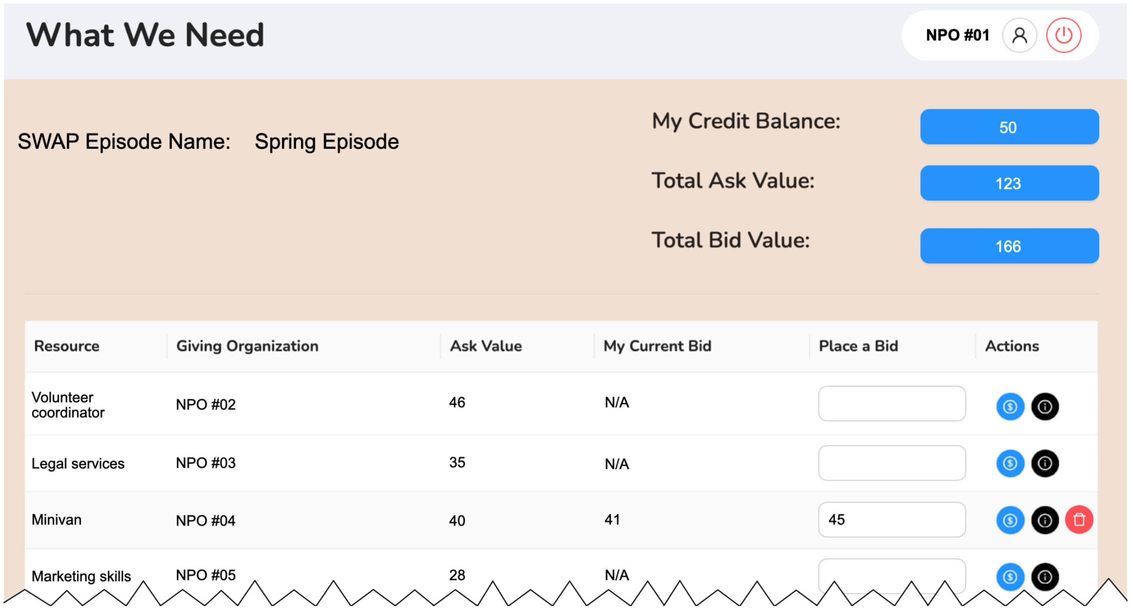
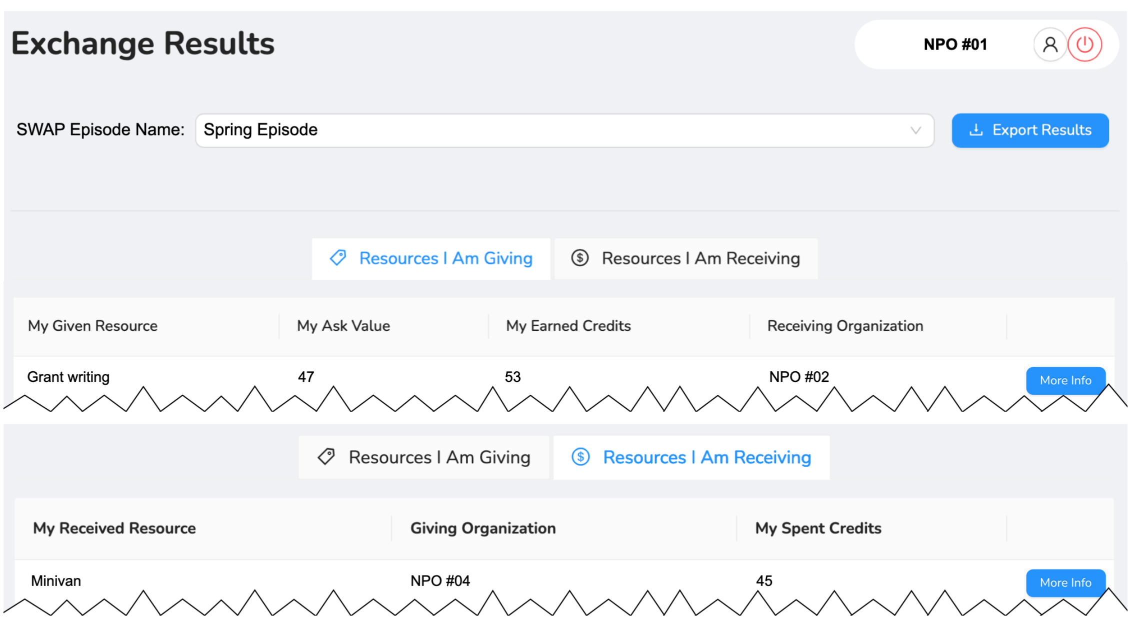


Figure 12: The “Exchange Results” view in SWAP publishes exchange results for receiving and giving.



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({$R-1$,...,$R+2$})=1	Pr({$R-1$,...,$R+2$})=0.5 Pr({$R+3$,...,$2R$})=0.5	Pr({$R+3$,...,$2R$})=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.

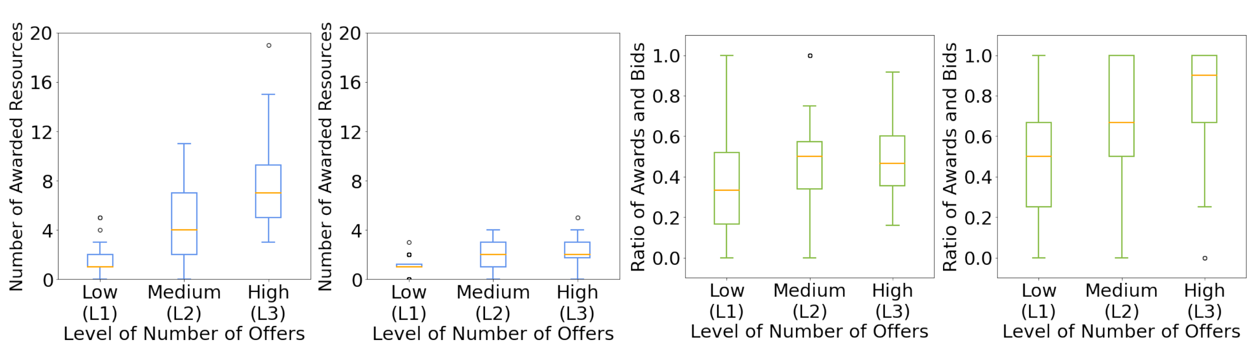
Table 6: Varied factors and levels regarding offer and bid behaviors and cohort size.

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 .

(a) Market Context-Model Pair One (M1). (b) Market Context-Model Pair Two (M2). (c) Market Context-Model Pair One (M1). (d) Market Context-Model Pair Two (M2).



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

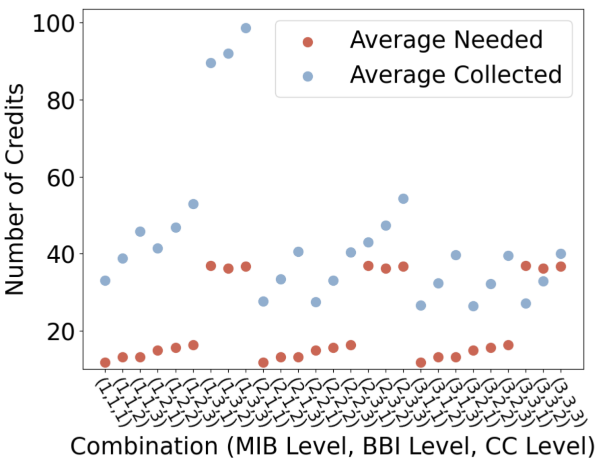
The findings of our experiments are reflected in and applied to two concrete cohort scenarios. The first scenario involves a newly established cohort where NPOs are learning about one another and understanding their respective resource needs. In this scenario, NPOs may engage conservatively, offering 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.

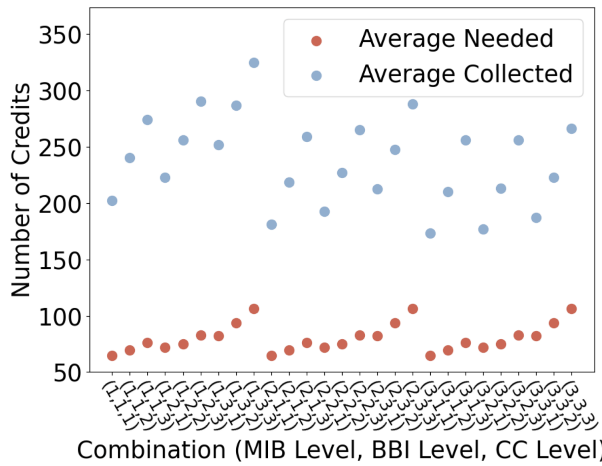
The second scenario, depicted in Figure 14b, involves a well-established cohort where NPOs are familiar with market dynamics. This market is characterized by a higher volume of offering, bidding, and resource exchanges, resulting in a thick and active market. Consequently, sufficient credits are always 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 $\sum_{t=1}^{3m} s_t x_{i_t,j}^{k_t} \le B$ 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. ■