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Decentralized Matching with Transfers: Experimental and Noncooperative Analyses†

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We experimentally examine the Becker-Shapley-Shubik two-sided matching model. In the experiment, the aggregate outcomes of matching and surplus are affected by whether equal split is in the core and whether efficient matching is assortative; the canonical cooperative theory predicts no effect. In markets with an equal number of participants on both sides, individual payoffs cannot be explained by existing refinements of the core, but are consistent with our noncooperative model's predictions. In markets with unequal numbers of participants, noncompetitive outcomes, are not captured by the canonical cooperative model, but are included in the set of predictions in our noncooperative model. (*JEL* C71, C72, C78)

The transferable-utilities (TU) two-sided matching model, developed by Shapley and Shubik (1972) and Becker (1973), has been widely used to study marriage and labor markets, both theoretically and empirically.[1] There is increasing interest in testing the model's predictions on stable/core matching and bargaining outcomes[2] in laboratory experiments, which have the advantage of creating a controlled environment that allows researchers to better understand the scope and limitations of a theory despite the small number of participants and the low incentives provided (Roth 2015). This study conducts one of the first comprehensive experiments on the

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[1] For a comprehensive overview of the TU matching model and its applications, see the following surveys and monographs: Galichon (2016); Chiappori and Salanié (2016); Chade, Eeckout, and Smith (2017); and Chiappori (2017). The model has been applied to explain observed assortative matching in characteristics such as education, height, race, income, and blood type (Becker 1973; Siow 2015; Eika, Mogstad, and Zafar 2019; Pollak 2019; Hou et al. 2022); cross-country differences in income and growth (Kremer 1993); increases in CEO pay (Gabaix and Landier 2008); and college and career choices (Chiappori, Iyigun, and Weiss 2009; Zhang 2020, 2021; Zhang and Zou 2023).

[2] A matching and bargaining outcome is stable (also known as being in the core) if no pair of agents has an incentive to deviate from their respective partners to form a new pair.

TU matching model and tests alternative noncooperative and behavioral theories on experimental findings that cannot be rationalized by the canonical cooperative theory.

Our experimental investigation starts with the smallest *balanced* markets with nontrivial matching possibilities: markets with three subjects on each side. Then we study *imbalanced* markets with three subjects on one side and four on the other. To mimic the TU matching market, we reduce frictions by allowing subjects to propose to anyone on the opposite side of the market with any division of the surplus, and no match becomes permanent until the end of the game.[3] To ensure the robustness of our main findings, we run two waves of experiments that differ in game-ending rules and payment rules.

According to the canonical theory, different surplus configurations of the market should not affect people's abilities to achieve efficient matching or stable bargaining outcomes. However, in practice, several factors may have an impact. We first investigate how two features affect matching and bargaining outcomes in balanced markets: (i) whether efficient matching is assortative and (ii) whether an equal split of each efficiently matched pair's surplus is stable/in the core. To do so, we use a two-by-two comparison. First, we hypothesize that the configurations that admit an assortative efficient matching are more straightforward and intuitive, since sorting has frequently been observed in practice. It is therefore important to investigate whether subjects in a controlled experiment indeed find it easier to match when assortative matching is available. Second, we note that an equal division of every efficiently matched pair's surplus is the pairwise Nash (1950) bargaining outcome, and is also the limit outcome of pairwise Rubinstein (1982) bargaining when subjects are infinitely patient, so subjects may find it easier and strategically more plausible to achieve and maintain such an outcome if it is also in the core.[4]

Our experiment finds that the probability of being matched and the probability of achieving efficient matching are significantly higher in markets with pairwise equal splits in the core and, to a lesser extent, in markets with assortative efficient matching. These differences are stronger in wave 1 of the experiment with time limits than in wave 2 without time limits. In markets with pairwise equal splits in the core, most subjects propose equal splits and most accepted proposals feature equal splits. In contrast, in other markets, equal splits are less commonly proposed and less commonly accepted. These results suggest that having pairwise equal splits in the core and assortative efficient matching are important determinants of matching and bargaining outcomes in TU matching markets. Moreover, subjects tend to reach certain bargaining outcomes in the core, but existing single-valued and set-valued refinements of the core do not systematically capture the experimental payoffs.

Next, we investigate imbalanced markets. We duplicate the agent with the lowest bargaining power in each of the four balanced markets, which results in three

[3] The features of the experiment described capture, for example, a labor market in which firms and workers—or a venture capital market in which entrepreneurs and investors—are negotiating deals simultaneously.

[4] There may be additional reasons for equal splits, including but not limited to complexity, social preferences, and focal points. When pairwise equal splits are not in the core, inequality aversion may prohibit people from forming a pair. For example, in the marriage market, a man and a woman who divide their joint surplus unequally may consider the division unfair and choose to end the relationship, even if they cannot do better by matching with someone else. This phenomenon can be explained by inequality aversion, as first introduced in the economics literature by Fehr and Schmidt (1999) and Bolton and Ockenfels (2000).

agents on one side and four agents on the other.[5] According to the canonical theory, competition between the two duplicate agents would be expected to drive down their payoffs, even to zero. However, in the experiment, their payoffs rarely (i.e., in less than 1 percent of instances) reach zero in the experiment. In fact, in wave 1, their payoffs often do not differ much from their payoffs in balanced markets, as if there were no competition. Even when their payoffs are lower than their payoffs in balanced markets, they are significantly above zero.

Considering the discrepancy between the experimental data and the canonical theory, and motivated by the need to match the experimental payoffs and to understand the general pattern of interaction, we extend the bilateral bargaining model of Rubinstein (1982) to the matching market. This captures the dynamic bargaining process in our experimental design. Our noncooperative bargaining-in-matching model features a unique equilibrium in balanced markets when the delay frictions are sufficiently small. Whenever the outcome of pairwise equal splits is in the core, it is also our noncooperative model's predicted outcome as frictions vanish, because each pair essentially engages in Rubinstein bargaining with their partner when outside options do not influence their bargaining outcomes in equilibrium.[6] When the outcome of pairwise equal splits is not in the core, outside threats influence players' bargaining power with their partners. Our noncooperative model incorporates these outside options. Average experimental payoffs in balanced markets largely coincide with the payoffs in the unique equilibrium of our noncooperative model as frictions vanish.

For imbalanced markets, our noncooperative model has a continuum of equilibria that can explain these experimental observations: (i) a class of competitive equilibria in which competitors get (near) zero payoffs, (ii) a class of noncompetitive equilibria in which there is essentially no competition between competitors, and (iii) a class of partially competitive equilibria in which competitors receive positive payoffs between the payoffs in the previous two classes of equilibria. The noncompetitive and partially competitive equilibria are sustained by the credible threat that agents would fully compete if one deviates from the equilibrium. Such an equilibrium is not sustained in balanced markets, but is sustained in imbalanced markets because the threat to drive a competitor's payoff to zero is credible as part of the stable outcome only in imbalanced markets. These findings are largely consistent across the two waves of experiments, with slightly more zero payoffs in wave 2.

[5] A prominent application of imbalanced markets is a marriage market with an imbalanced sex ratio, in which low-income men tend to compete for wives. For example, Wei and Zhang (2011) find that the rising sex ratio in China can explain the increasing saving rates because Chinese parents with sons raise their savings competitively to increase their sons' attractiveness in the marriage market. In addition, biased sex ratio has been empirically documented to drive other competing behaviors such as dowries (Edlund 1999; Qian 2008; Wei and Zhang 2011; Corno, Hildebrandt, and Voena 2020). Furthermore, there are long-term consequences of a biased sex ratio (Grosjean and Khattar 2019). Another application is the labor market, in which low-skill workers, who are easy substitutes for one another, compete to be employed and receive low wages (Katz and Murphy 1992). The theoretical studies are of interest by themselves, going back to the situation with one buyer and two sellers (Shapley 1953; Shapley and Shubik 1972; Hendon and Tranaes 1991; Núñez and Rafels 2005; Leng 2023).

[6] This result helps explain without behavioral assumptions the widespread observation of equal splits. Recent papers by Elliott and Nava (2019) and Talamàs (2020) take a noncooperative approach to model matching markets but consider different bargaining protocols and agent replenishment in the market. Both papers reach similar conclusions regarding the stability of the pairwise equal splits outcome when the outcome is in the core. See also Nax and Pradelski (2015), who show that a simple dynamic learning process can lead to equitable core outcomes.

In addition, we explore the possibility of fairness concerns in rationalizing the experimental results. We construct a matching model in which subjects have Fehr and Schmidt (1999) inequality aversion preferences. We define a "fair core" as the prediction of the model and compare it to the experimental findings. Overall, adding fairness concerns may further reinforce the robustness of matching with equal splits in the core and explain why players' payoffs in imbalanced markets are away from zero. However, the model cannot be used as the sole explanation of the experimental behavior, because (i) in balanced markets, the fair core still has a wide range of predictions, and (ii) in imbalanced markets, although the fair core no longer allows zero payoffs for players on the long side of the market, the prediction is still a singleton, which differs from the observed range of experimental payoffs.

After the literature review, the remainder of the paper is organized as follows. Section I presents definitions and testable implications of the canonical TU matching model. Section II introduces the experimental design, procedures, and hypotheses. Section III presents experimental results on matching and bargaining outcomes. Section IV discusses our noncooperative and inequality aversion models and their fit with balanced and imbalanced markets in the experiment. Section V concludes and discusses additional experimental results.

Most matching experiments focus on nontransferable-utilities (NTU) matching models, following Gale and Shapley (1962), and take a market-design perspective to understand the stability, efficiency, and strategyproofness of different algorithms implemented by a central clearinghouse. Roth (2015) and Hakimov and Kübler (2019) provide recent surveys on this topic. A few studies consider decentralized NTU markets in which both sides can make offers, such as Echenique and Yariv (2013); Chen et al. (2015); and Pais, Pintér, and Veszteg (2020). Experimental studies of trading markets (Hatfield, Plott, and Tanaka 2012, 2016; Plott et al. 2019) have also found that in the absence of a competitive equilibrium, markets tend to conform to the stable outcomes predicted by theory (Kelso and Crawford 1982; Hatfield et al. 2013).

Several experiments test the TU matching model. Nalbantian and Schotter (1995) set up an experiment that mimics the baseball free agency market with three "managers" and three "players" negotiating salaries via phone, which effectively creates a decentralized TU matching market with incomplete information. In their experiment, subjects do not have complete information on the matching surpluses, and they negotiate through phone calls to reach permanent agreements. In contrast, our subjects have complete information on the matching surpluses and make offers that are first temporarily accepted, which reduces matching frictions. In addition, the negotiation process in our experiment is more structured than theirs, which allows us to obtain rich information on the details of subjects' proposals and their decisions to accept or reject. Otto and Bolle (2011) study the final outcome of six different two-by-two matching markets with price negotiation and verbal communication. In contrast, we focus on decentralized two-sided matching markets that do not feature verbal negotiation, but allow negotiation through the strategic acceptance/rejection of competing offers from potential matches. This enables us to document subjects' behavior during the negotiation process. Furthermore, our focus on more than two agents on both sides allows us to have nonassortative efficient matching patterns that cannot be captured by two-by-two markets. Dolgopolov et al. (2024)

study a three-by-three assignment matching market and investigate the market outcomes under three institutions (double auctions, posted prices, and decentralized communication), which differ from ours. They find that Nash outcomes are commonly observed under double-auction rules, though efficient outcomes are not always achieved; however, markets with communication achieve higher efficiencies on average. Agranov and Elliott (2021) consider three two-by-two markets, but in their decentralized bargaining process, following Elliott and Nava (2019), if a pair is matched, both players leave the market. Hence, the incentives in their setting differ from ours. Agranov et al. (2023) compare matching under complete and incomplete information and find that incomplete information and submodularity jointly hinder the efficiency and stability of matching. However, their comparison is focused on two assortative markets with and without pairwise equal splits in the core. We instead consider eight different markets with complete information, which allows us to examine the role of assortativity, equal splits, and imbalance.

The experimental literature on imbalanced markets is scarce. Yan, Friedman, and Munro (2016) reveal that agents on the short side do not capture the entire surplus, but the paper focus is on the comparison between different centralized trading mechanisms. Leng (2023) conducts experiments on two-by-one markets using the bargaining protocol of Perry and Reny (1994) that supposedly achieves the core outcome and finds that, contrary to the theoretical prediction but similar to the experimental results of our three-by-four markets, the core outcome is not achieved. This means that agents on the short side of the market do not capture the entire surplus.

In summary, our paper is distinct from other papers in several respects and provides a comprehensive study of balanced and imbalanced matching markets. Overall, our paper contributes to the literature in three ways. First, we manipulate market configurations to investigate the impact of two features—having pairwise equal splits in the core and assortativity—on matching and bargaining outcomes. Second, our findings show that agents tend to achieve certain bargaining outcomes in the core in balanced matching markets, and our noncooperative model features a unique equilibrium that aligns with these outcomes. Third, we find that agents can achieve a range of bargaining outcomes both inside and outside the core in imbalanced matching markets, and our noncooperative model helps rationalize such multiplicities.

I. Canonical Cooperative Theory

We briefly review the canonical cooperative TU matching model based on Shapley and Shubik (1972) and Becker (1973) to introduce notation, terms, and main testable implications. There are two sides that consist of n_M men, $M = \{m_1, \cdots, m_{n_M}\}$, and n_W women, $W = \{w_1, \cdots, w_{n_W}\}$. The entire set of players is denoted by $I = M \cup W$. We say that a market is **balanced** if $n_M = n_W$ and **imbalanced** otherwise. For any man $m \in M$ and woman $w \in W$, they produce a total surplus of s_{mw}. The surpluses of all pairs can be summarized by a surplus matrix $s = \{s_{mw}\}_{m \in M, w \in W}$. Each agent gets zero when unmatched and gets a payoff that depends on the division of the surplus when matched. Note that the surplus matrix s describes the entire market, so we can refer to a matching market simply by s.

DEFINITION 1 (Stable outcome): *A* **stable outcome** *of market s is described by a* **stable matching** $\mu : I \to I \cup \{\emptyset\}$ *and vectors of* **stable/core payoffs** $u : M \to \mathbb{R}$ *and* $v : W \to \mathbb{R}$ *such that* (*i*) (*individual rationality*) *each person gets at least as much as staying single:* $u_m \geqslant 0$ *for all* $m \in M$ *and* $v_w \geqslant 0$ *for all* $w \in W$; (*ii*) (*surplus efficiency*) *each couple exactly divides the surplus:* $u_m + v_w = s_{mw}$ *if* $m = \mu(w)$ *and* $w = \mu(m)$; *and* (*iii*) (*no blocking pair condition*) *each couple divides the total surplus in such a way that no man and woman pair has an incentive to form a new pair:* $u_m + v_w \geqslant s_{mw}$ *for any* $m \in M$ *and* $w \in W$.

There is always a stable outcome in the TU matching model, which serves as the benchmark theoretical prediction for each matching market. Stable matching and payoffs satisfy some easily testable properties, which we summarize below.

PROPOSITION 1 (Stable matching): *A matching is stable if and only if it is efficient; that is, it maximizes the total surplus. Equivalently, a matching* μ *is stable if and only if it is the solution to the linear programming problem* $\max_{\mu \in \mathcal{M}} \sum_{m \in M} s_{m\mu(m)}$, *where* $\mathcal{M}$ *is the set of feasible matching.*

COROLLARY 1 (Full matching): *If every element in the surplus matrix is positive, a stable matching is a* **full matching**; *that is, the number of matched pairs in the stable outcome reaches the maximum possible number.*

COROLLARY 2 (Efficient matching): *If there is a unique efficient matching, this matching is the unique matching in the stable outcome.*

We say that man m is higher ranked than man m'—i.e., $m > m'$—if $s_{mw} \geq s_{m'w}$ for any woman w with a strict inequality for some w; women's ranks are defined similarly. A key observation of Becker (1973) is that if surplus matrix s, after reordering according to rank, satisfies supermodularity, then a stable matching is positive-assortative, in that the highest ranked man is matched with the highest ranked woman, the second highest ranked man is matched with the second highest ranked woman, and the nth highest ranked man is matched with the nth highest ranked woman. To slightly abuse terminology for expositional convenience, we say that the surplus matrix is *assortative* if agents can be ranked and the matrix that is rearranged according to the ranks satisfies supermodularity. To formally define an assortative surplus matrix, we need to first define a reordered surplus matrix.

DEFINITION 2 (Reordered surplus matrix): *The surplus matrix* $\tilde{s}$ *is a* **reordered surplus matrix** *of surplus matrix s if there exists a pair of permutations* $\pi_M : M \to M$ *and* $\pi_W : W \to W$ *such that* $\tilde{s}_{\pi_M(m)\pi_W(w)} = s_{mw}$ *for any* $m \in M$ *and any* $w \in W$.

DEFINITION 3 (Assortative surplus): *Consider Condition* (*A*) *for a reordered matrix* $\tilde{s}$ *of matrix s:*

(A) $$\tilde{s}_{mw} + \tilde{s}_{m'w'} > \tilde{s}_{mw'} + \tilde{s}_{m'w} \quad \forall m, m' \in M \text{ and } w, w' \in W$$

s.t.

$$m > m' \text{ and } w > w'.$$

A reordered matrix $\tilde{s}$ *is* **positive-assortative** (*supermodular in* Agranov et al. 2023) *if Condition* (*A*) *is satisfied and* $\forall m, m' \in M, \forall w, w' \in W{:}m > m' \Rightarrow \tilde{s}_{mw} \geq (\leq) \tilde{s}_{m'w}$ *and* $w > w' \Rightarrow \tilde{s}_{mw} \geq (\leq) \tilde{s}_{mw'}$; *or* **negative-assortative** (*submodular in* Agranov et al. 2023) *if Condition* (*A*) *is satisfied and* $\forall m, m' \in M, w, w' \in W : m > m' \Rightarrow \tilde{s}_{mw} \geq (\leq) \tilde{s}_{m'w}$, *and* $w > w' \Rightarrow \tilde{s}_{mw} \leq (\geq) \tilde{s}_{mw'}$. *A matrix s is* **assortative** *if there exists a reordered matrix* $\tilde{s}$ *that is positive-assortative or negative-assortative. A matrix s is* **nonassortative** *or* **mixed** *if it is not assortative.*

PROPOSITION 2 (Stable/core payoffs): *The set of stable payoffs* (*Becker 1973*), *or equivalently the core* (*Shapley and Shubik 1972*), *is the set of solutions of the following linear programming problem:*

$$\min \sum_{m \in M} u_m + \sum_{w \in W} v_w \quad s.t.\ u_m + v_w \geqslant s_{mw}\ \forall m \in M \ \text{ and } \ w \in W.$$

With a finite number of agents, there is always a nonsingleton set of stable payoffs (given a positive surplus matrix). An equal split of the surplus for each pair in the stable matching is not always in the core (as some surplus matrices chosen in the experiment will show).

DEFINITION 4 (Pairwise equal splits in the core): **Pairwise equal splits is in the core** (**ESIC**) *of game s if there exists efficient matching* μ^* *such that payoffs* $u_m = s_{m\mu^*(m)}/2$ *for each matched* $m \in M$ *and* $v_w = s_{\mu^*(w)w}/2$ *for each matched* $w \in W$. *We say that* **pairwise equal splits is *not* in the core** (**ESNIC**) *of game s otherwise.*

The core is generically a nonsingleton set. Many solution concepts refine the core, but differ in their predictions. Examples in online Appendix A.1 demonstrate the differences in the refined solutions such as Shapley value (Shapley 1953), nucleolus (Schmeidler 1969), extreme points (Shapley and Shubik 1972), fair division point (Thompson 1980), kernel (Rochford 1984), and median stable matching (Schwarz and Yenmez, 2011). See Núñez and Rafels (2015) for a summary of solution concepts.

II. Experiment

In this section, we present the experimental design and procedures for the first wave of the experiment. The second wave, which has different ending and payment rules, will be introduced in Section IIIA.

A. *Treatment Design*

We use eight surplus configurations, as shown in Table 1. Each surplus configuration represents a different matching market. The four markets shown on the left-hand side of Table 1 are balanced, and the four on the right-hand side are imbalanced.

Table 1—Surplus Configurations in the Experiment

Assortative — Balanced markets (6 players) — ESIC — EA6	w_1	w_2	w_3
m_1	$\underline{\underline{30}}$	40	50
m_2	40	$\underline{\underline{60}}$	80
m_3	50	80	$\underline{\underline{110}}$

Assortative — Balanced markets (6 players) — ESNIC — NA6	w_1	w_2	w_3
m_1	90	80	$\underline{\underline{70}}$
m_2	80	$\underline{\underline{60}}$	40
m_3	$\underline{\underline{70}}$	40	10

Assortative — Unbalanced markets (7 players) — ESNIC — EA7	w_1	w_2	w_3	w_4
m_1	$\underline{30}$	40	50	$\underline{30}$
m_2	40	$\underline{\underline{60}}$	80	40
m_3	50	80	$\underline{\underline{110}}$	50

Assortative — Unbalanced markets (7 players) — ESNIC — NA7	w_1	w_2	w_3	w_4
m_1	90	80	$\underline{70}$	$\underline{70}$
m_2	80	$\underline{\underline{60}}$	40	40
m_3	$\underline{\underline{70}}$	40	10	10

Mixed — EM6	w_1	w_2	w_3
m_1	30	$\underline{\underline{60}}$	80
m_2	60	70	$\underline{\underline{100}}$
m_3	$\underline{\underline{40}}$	40	60

Mixed — NM6	w_1	w_2	w_3
m_1	90	$\underline{\underline{60}}$	30
m_2	$\underline{\underline{100}}$	50	30
m_3	80	60	$\underline{\underline{40}}$

Mixed — EM7	w_1	w_2	w_3	w_4
m_1	30	$\underline{\underline{60}}$	80	30
m_2	60	70	$\underline{\underline{100}}$	60
m_3	$\underline{40}$	40	60	$\underline{40}$

Mixed — NM7	w_1	w_2	w_3	w_4
m_1	90	$\underline{\underline{60}}$	30	30
m_2	$\underline{\underline{100}}$	50	30	30
m_3	80	60	$\underline{40}$	$\underline{40}$

Notes: Assortative: Efficient matching is assortative; Mixed: Efficient matching is not assortative; ESIC: equal-splits in the core; ESNIC: equal-splits not in the core. For balanced markets, the double-underlined surpluses in each configuration show pairings in the unique efficient matching. For unbalanced markets, the double-underlined surpluses in each configuration show pairings that are for sure part of efficient matching, and one of the two single-underlined surpluses in each configuration constitutes the last pair of efficient matching.

Row players are denoted by (cold color) squares and column players by (warm color) circles. In the experiment, we use squares and circles of different colors and do not index the subjects. In the exposition, we refer to row players as men and column players as women. For example, the first square is denoted by m_1.

For balanced markets, the double-underlined surpluses in each configuration show pairings in the unique efficient matching. We vary the configurations in two dimensions: (i) whether efficient matching is assortative, as defined in Definition 3, and (ii) whether the outcome of pairwise equal splits is in the core, as defined in Definition 4. Hence, each market (i) has pairwise equal splits in the core (ESIC, or simply E) or pairwise equal splits not in the core (ESNIC, or simply N) and (ii) is assortative (A) or mixed (M). We refer to the four configurations by EA6, EM6, NA6, and NM6. We also design the surpluses to provide consistency across markets: The maximum total surplus that all agents can obtain is 200; the average total surplus that all agents can obtain is 180 if they are matched fully and randomly; and the minimum total surplus they can obtain if they are all matched is 160.

The only difference between imbalanced and balanced markets is that there is one more (warm color) circle player in each imbalanced market. Specifically, each of the four surplus matrices replicates the column player that yields the lowest surplus in the corresponding balanced market setting. Though pairwise equal splits are no longer in the core (because the duplicate players would get zero in the core), we refer to the four markets by EA7, NA7, EM7, and NM7 to clarify the connection with their balanced counterparts.

We employ a between-subjects design for both balanced and imbalanced markets and a within-subjects design for the four different configurations of each market type. That is, subjects play either the four balanced markets or the four imbalanced markets, but they play the four markets in different orders. Using the Latin square method,[7] for balanced and imbalanced markets, we each have four treatment orders:

	1	2	3	4
Treatment 1	EA	NA	EM	NM
Treatment 2	NM	EA	NA	EM
Treatment 3	EM	NM	EA	NA
Treatment 4	NA	EM	NM	EA

At the beginning of the experiment, subjects are randomly selected to form a group (of six or seven), and this grouping remains fixed throughout the experiment. They remain anonymous, and their roles can change from round to round. Subjects within a group play the four markets in the order that corresponds to their assigned treatment. Each market is played for seven rounds, so they play 28 rounds in total.[8] At the beginning of each round, each subject is randomly assigned a (color) shape that represents their role. A (cold color) square can only be matched with a (warm color) circle. Each market lasts at least three minutes. Within the three-minute interval, anyone can propose to anyone on the opposite side. To propose, a subject clicks the color they wish to propose to and decides the division of surplus. The receiver of a proposal has 30 seconds to accept or reject. When the proposer is waiting for the response, the proposer cannot make a new proposal to anyone. If a proposal is rejected, both sides are free to make and receive new offers.

If a proposal is accepted, a temporary match is reached; information on the temporary match and division of the surplus is shown to everyone in the market. When a temporary match is reached, both subjects can still make and receive proposals. One can always break their current temporary match by forming a new temporary match (either by proposing to a new person and being accepted or by accepting another proposal). A market ends at the three-minute mark and all temporary matches become permanent, unless someone is released from a temporary match in the last 15 seconds; in that case, they have 15 additional seconds to make a new proposal. If another subject is bumped from their temporary match as a result of the new proposal, the bumped subject gets a chance to make a proposal. This process of adding 15 seconds continues until no new proposal is accepted. Subjects can see the history of final matches in previous rounds.[9]

[7] We thank Yan Chen for this suggestion.

[8] One reason we choose seven rounds for each market is to ensure an ex ante equal opportunity for subjects in imbalanced markets, since one of the seven subjects is for sure unmatched and gets zero payoff in each round.

[9] To be clear, historical information is based on roles (squares and circles) but not on individual subjects, so there is no way to establish a bargaining style or reputation across periods. Subjects may learn better the overall structure of the game over time and consequently perform better (as suggested by the experimental results), but they cannot learn about any particular individual over time.

B. *Procedures*

The experiment was conducted at the Shanghai University of Finance and Economics. Chinese subjects were recruited from the subject pool of the Economics Lab through Ancademy, a platform for social sciences experiments; most subjects installed and used the app on their phones. In the first wave of the experiment, 296 subjects participated: 156 in balanced markets and 140 in imbalanced markets. Each subject participated only once. We ran eight sessions for the balanced markets and six sessions for imbalanced markets. In each session, we ran three to six independent markets. For balanced markets, the number of times each treatment order is used is seven, seven, six, and six, which yields 728 individual rounds of games. For imbalanced markets, we used each treatment order five times, yielding 560 individual rounds. Subjects were mostly undergraduate students from various fields of study.

The experiment was computerized using z-Tree (Fischbacher 2007) and conducted in Chinese. Upon arrival, each subject was randomly assigned a card with their table number and seated in the corresponding cubicle. Prior to the start of the experiment, subjects read and signed a consent form agreeing to their participation. All instructions were displayed on their computer screens. Control questions were conducted to check their understanding of the instructions. Online Appendix A.2 contains English translations of the instructions and screenshots.

Subjects were paid the sum of their payoffs in 28 rounds at an exchange rate of 12 units of payoffs to CNY 1 in balanced markets. To keep the average earnings comparable between balanced and imbalanced markets, we lowered the exchange rate of the experimental currency from 12 to 10 in imbalanced markets. Everything else is kept the same as in balanced markets. After finishing the experiment, subjects received their earnings in cash. Average earnings were CNY 85 (equivalent to about \$12, or about \$20 PPP-adjusted) for balanced markets, and CNY 93 for imbalanced markets (equivalent to about \$14, or about \$23 PPP-adjusted). Each session lasted around two hours.

C. *Discussion*

We briefly discuss the rationale behind some elements of our design for the first wave of the experiment. First, we impose the three-minute soft deadline primarily for practical purposes. In each experimental session, to ensure ex ante equal opportunity for subjects in imbalanced markets, each market type is played seven rounds for a total of 28 rounds. If the average duration of each round is three minutes, we can control the entire duration of the experiment within two hours (including time spent explaining instructions and paying subjects). Imposing a soft deadline inevitably creates frictions. We change the game-ending rule in the second wave of the experiment to a 30-second inactivity rule, consistent with Agranov et al. (2023).

Second, we pay subjects for every round for fairness in imbalanced markets. If we instead pay only one random round, this would result in a zero payoff for at least one subject. Paying the sum of payoffs for all rounds with feedback on earnings can potentially lead to income effects, which may push for equal splits. Nevertheless, the problem is mitigated by varying the order of the games and we do see significant differences in how often subjects end up with equal splits in different markets. In the second wave of the experiment, we change the payment rule to paying randomly for one round for each of the four configurations.

Third, one may vary the appearance of each surplus matrix with reordered rows and columns to avoid the potential appearance bias that matches on the diagonal are more likely to form. However, each six-player surplus matrix has $3! \times 3! = 36$ ways of appearing, and each seven-player surplus matrix has $3! \times 4!/2 = 72$ ways of appearing, so there are $4! \times \left(72^4 + 36^4\right) \approx 6.85 \times 10^9$ possible order and appearance treatments. It is unclear how to simultaneously vary the appearance of each matrix and the ordering of different matrices using a reasonable number of participants. Our results suggest that subjects are not making decisions based on the heuristic of matching with diagonal partners. There does not appear to be a higher frequency of diagonal pairs when the pairs are not efficient (Table 2, panel A). Furthermore, the overall more efficient outcomes in EM6 (off-diagonal efficient matching) over NA6 (diagonal efficient matching) suggest that the appearance bias does not have a significant effect on matching and bargaining outcomes.

III. Results

In this section, we focus on the two most important aspects of the model: (i) the aggregate outcomes of matching and surplus and (ii) individual payoffs. We discuss other experimental findings in online Appendix D.

A. *Aggregate Outcomes: Matching and Surplus*

Wave 1.—Table 2, panel A presents the raw distributions of matches and singles. We observe significant instances of singles and inefficient matches.

The canonical theory predicts (i) full matching (Corollary 1), (ii) efficient matching and efficient surplus (Corollary 2), and (iii) a stable matching and bargaining outcome (Proposition 1). We test these predictions in several ways using different outcome measures. We state the hypotheses below.

HYPOTHESIS 1 (Full matching): (*a*) *The number of matched pairs is the maximum feasible number;* (*b*) *Full matching is always achieved.*

Row 1a of Table 2, panel B shows the average number of matched pairs by market type, which ranges from 2.40 in NM6 to 2.93 in EA7. For each of the eight market types, we can reject the hypothesis that the maximum number of matched pairs is achieved. We observe comparable results in previous experiments.[10]

Nonetheless, the market does not completely break down. Row 1b of Table 2, panel B shows the proportion of full matching by market type. It ranges from 41

[10]For instance, Nalbantian and Schotter (1995) consider a three-by-three market with pairwise equal splits in the core and nonassortative efficient matching (i.e., a market of type EM6). In their experiment, 9.3 percent (14 of 150 potential matches) fail to match, which translates to 2.79 pairs, compared with 2.76 pairs in our experiment's EM6 market.

Table 2—Aggregate Outcomes: Wave 1

Panel A. Frequency of being matched and unmatched in the experiment: wave 1

EA6

	w_1	w_2	w_3	∅
m_1	92%	4%	1%	4%
m_2	4%	87%	3%	5%
m_3	1%	5%	92%	2%
∅	4%	4%	4%	

NA6

	w_1	w_2	w_3	∅
m_1	2%	21%	70%	7%
m_2	27%	51%	6%	16%
m_3	68%	10%	2%	19%
∅	3%	18%	21%	

EA7

	w_1	w_2	w_3	w_4	∅
m_1	53%	1%	1%	44%	1%
m_2	8%	72%	6%	9%	4%
m_3	0%	11%	88%	0%	1%
∅	39%	16%	5%	47%	

NA7

	w_1	w_2	w_3	w_4	∅
m_1	1%	9%	46%	42%	1%
m_2	16%	59%	8%	9%	8%
m_3	76%	9%	0%	1%	14%
∅	6%	23%	46%	47%	

EM6

	w_1	w_2	w_3	∅
m_1	0%	83%	8%	9%
m_2	3%	8%	85%	4%
m_3	91%	1%	0%	8%
∅	7%	8%	7%	

NM6

	w_1	w_2	w_3	∅
m_1	20%	40%	9%	31%
m_2	75%	2%	6%	17%
m_3	3%	47%	37%	13%
∅	1%	12%	48%	

EM7

	w_1	w_2	w_3	w_4	∅
m_1	0%	83%	11%	0%	6%
m_2	9%	4%	74%	8%	4%
m_3	51%	1%	0%	44%	3%
∅	39%	11%	15%	48%	

NM7

	w_1	w_2	w_3	w_4	∅
m_1	23%	56%	6%	4%	11%
m_2	71%	2%	3%	4%	20%
m_3	1%	23%	32%	39%	5%
∅	4%	19%	59%	54%	

Note: In each table, each cell not in the last row or column indicates the percentage of markets in which a pair has formed between the row player and column player. The last row reports the percentage of markets in which each respective column player is unmatched, and the last column reports the percentage for each row player.

	EA6	EM6	NA6	NM6	EA7	EM7	NA7	NM7
Panel B. Tests of hypotheses on aggregate outcomes: wave 1								
1a: # matched pairs=3	2.88	2.79	2.58	2.40	2.93	2.86	2.78	2.64
	(4.04)	(5.61)	(8.84)	(20.91)	(2.52)	(4.79)	(4.61)	(8.18)
1b: full matching=1	0.88	0.79	0.58	0.41	0.94	0.86	0.78	0.64
	(4.04)	(5.61)	(8.84)	(21.02)	(2.65)	(4.79)	(4.61)	(8.18)
2a: # efficiently matched pairs=3	2.71	2.59	1.89	1.52	2.56	2.53	2.23	1.99
	(4.91)	(6.43)	(11.31)	(20.92)	(5.36)	(5.64)	(7.92)	(11.97)
2b: efficient matching=1	0.83	0.74	0.43	0.26	0.71	0.69	0.55	0.46
	(4.58)	(6.70)	(11.40)	(22.69)	(5.51)	(6.01)	(8.64)	(10.81)
2c: % surplus achieved=1	0.96	0.93	0.87	0.84	0.95	0.92	0.91	0.87
	(4.36)	(5.45)	(9.57)	(18.60)	(3.94)	(5.42)	(5.85)	(8.57)
3a: stable outcome=1	0.76	0.54	0.07	0.05	0.00	0.00	0.00	0.00
	(6.09)	(10.02)	(47.22)	(53.96)	(·)	(·)	(·)	(·)
clusters	26	26	26	26	20	20	20	20

Note: t statistics in parentheses; standard errors clustered at group level.

percent in NM6 to 94 percent in EA7. For every market type except NM6, three pairs are matched in more than 58 percent of the rounds. In almost all games, there are more than two matched pairs. There is one matched pair in three of the 1,288 games (less than 0.3 percent of all games): two NM6 games of the 728 balanced market games and one EA7 game of the 560 imbalanced market games.

In a frictionless setting, we should expect that efficient matching—even if it is not unique—is always reached. It goes without saying that this prediction is rejected with the observation that some subjects do not match. Hence, we also test a more restrictive hypothesis: Some subjects may remain unmatched—and we remain agnostic about the reason—but when the maximum feasible number of matches is reached, the cooperative model predicts efficient matching. We report additional results in Table B1a in online Appendix B.

HYPOTHESIS 2: (*a*) *The number of efficiently matched pairs is the maximum feasible number*; (*b*) *Efficient matching is always achieved*; (*c*) *Efficient surplus is achieved. These hypotheses also hold given full matching.*

Rows 2a–2c of Table 2, panel B test these hypotheses. Row 2a shows that the number of efficiently matched pairs ranges from 1.52 (in NM6) to 2.71 (in EA7), far from the maximum number of 3. Row 2b provides a breakdown of the types of matching with respect to the number of efficiently matched and inefficiently mismatched pairs. In all market types except NA6 (43 percent), NM6 (26 percent), and NM7 (46 percent), efficient matching is achieved in the majority of rounds. Row 2c shows that the efficiency loss due to inefficient matches is statistically significant: The total surplus achieved ranges from 92 percent (EM7) to 96 percent (in EA6) in ESIC markets, and from 84 percent (in NM6) to 91 percent (NA7) in ESNIC markets.

An outcome is stable when not only the matching is efficient, but also the combination of individual payoffs derived from pairwise surplus division is in the core. Hence, reaching a stable outcome—efficient matching along with a stable division of surpluses—is more stringent than achieving efficient matching. Because the payoffs are transferable, the matching in any stable outcome is necessarily efficient.

HYPOTHESIS 3: (*a*) *A stable outcome is achieved*; (*b*) *A stable X outcome—an outcome in which no pair of agents can improve their joint payoffs by more than X units—is achieved*.

Row 3a of Table 2, panel B shows the probability that an outcome is stable. In EA6 and EM6—the balanced ESIC markets—in the majority of cases, subjects divide up the surplus in a way that cannot be improved upon by any blocking pair (76 percent and 54 percent, respectively).[11] However, in NA6 and NM6—the balanced ESNIC markets—efficient matching is achieved less frequently, and even when it is achieved, blocking pairs are more likely to exist.

In our imbalanced markets, stable outcomes always involve a matched subject and an unmatched subject who gets zero payoff. Strictly speaking, a stable outcome is not reached in any imbalanced markets in wave 1 of our experiment, because no matched subject receives zero. Even with a looser definition of stability, a significant portion of imbalanced markets have blocking pairs that can improve by more than 10 units of payoff, but they do not form a match by the end of the game. See Table B1a in online Appendix B. This significant discrepancy between theory and

[11] Row 3a" of online Appendix Table B1a shows the probability that an outcome is stable, conditioning on efficient matching. The conditional probabilities are 92 percent in EA6 and 74 percent in EM6.

experiment in stable payoffs suggests that players are behaving in a way that is systematically different from what the cooperative theory predicts.

Wave 2.—The results in Section IIIA show that the matching rate and efficiency rate differ significantly from 100 percent. One plausible reason for this could be that some subjects may not have enough time to react and form new matches after they are released by the end of the three minutes, even with the additional 15 seconds provided. To make sure that frictions created by the ending rule do not drive our main findings on matching patterns and surplus divisions, we run an additional wave of the experiment with an alternative ending rule as a robustness check.

In wave 2 of the experiment, we use the same eight surplus configurations as in wave 1. We again employ a between-subjects design for the balanced and imbalanced markets, and a within-subjects design for the four different configurations of each market type. The main design difference lies in the ending rule: In wave 2, the market ends when no new proposals are made within 30 seconds. In imbalanced markets, to potentially shorten the market length, we added a "Move to the next round" button. As soon as six of the seven subjects press this button, the market ends. This means that the market continues as long as it is active, and ends when there is no activity for a certain period of time. To adjust to the change in the ending rule, we make another change in the design: In wave 1, the receiver of a proposal has 30 seconds to accept or reject the proposal; in wave 2, we shorten the time to 15 seconds. This is to avoid a scenario in which the market may end immediately if the receiver does not respond within 30 seconds, which leaves the proposer no time to make a new proposal. This scenario would create additional frictions in the market, so we aim to avoid it.

In addition to changing the ending rule, we also reduce the number of rounds for which subjects are paid in order to minimize the influence of income effects and coordination on surplus division. In wave 1, we pay the sum of payoffs for all rounds, but in wave 2, we only pay subjects four randomly selected rounds, one for each configuration. This helps to ensure that the results are not influenced by these factors.

The experiment was again conducted at the Shanghai University of Finance and Economics. In total, 130 subjects participated: 60 in balanced markets and 70 in imbalanced markets. Therefore, there were exactly 10 independent groups for each market type. Each subject participated only once, and did not participate in the wave 1 experiment. We ran two sessions for the balanced markets and three sessions for the imbalanced markets. Because markets tended to last longer in wave 2, we let subjects play five rounds instead of seven rounds for each configuration, for 20 rounds in total.[12] At the end of the experiment, subjects were paid for four randomly selected rounds out of the total rounds they played at the exchange rate of 1 unit of payoff to CNY 1. Average earnings were CNY 140 (equivalent to about $19, or about $32 PPP-adjusted). On average, the sessions lasted 2.5 hours. The balanced markets took 3.5 minutes per market and the imbalanced markets took 5.1 minutes per market.

[12] In balanced markets, we initially planned to let subjects play 28 rounds (seven rounds for each configuration). However, due to a technical mistake, subjects ended up playing five rounds for each of the four configurations, followed by eight rounds of the fourth configuration. We dropped these last eight rounds from our experimental analysis.

Table 3—Aggregate Outcomes: Wave 2

Panel A. Frequency of being matched and unmatched in the experiment: wave 2

EA6

	w_1	w_2	w_3	Ø
m_1	98%	0%	0%	2%
m_2	0%	96%	2%	2%
m_3	0%	2%	98%	0%
Ø	2%	2%	0%	

NA6

	w_1	w_2	w_3	Ø
m_1	6%	26%	68%	0%
m_2	30%	54%	16%	0%
m_3	64%	14%	10%	12%
Ø	0%	6%	6%	

EA7

	w_1	w_2	w_3	w_4	Ø
m_1	66%	6%	0%	26%	2%
m_2	6%	68%	16%	10%	0%
m_3	0%	16%	84%	0%	0%
Ø	28%	10%	0%	64%	

NA7

	w_1	w_2	w_3	w_4	Ø
m_1	0%	10%	48%	42%	0%
m_2	12%	66%	10%	12%	0%
m_3	86%	12%	2%	0%	0%
Ø	2%	12%	40%	46%	

EM6

	w_1	w_2	w_3	Ø
m_1	0%	96%	2%	2%
m_2	0%	2%	98%	0%
m_3	100%	0%	0%	0%
Ø	0%	2%	0%	

NM6

	w_1	w_2	w_3	Ø
m_1	16%	50%	22%	12%
m_2	82%	0%	8%	10%
m_3	0%	46%	48%	6%
Ø	2%	4%	22%	

EM7

	w_1	w_2	w_3	w_4	Ø
m_1	2%	80%	16%	0%	2%
m_2	10%	10%	72%	6%	2%
m_3	46%	0%	0%	52%	2%
Ø	42%	10%	12%	42%	

NM7

	w_1	w_2	w_3	w_4	Ø
m_1	2%	92%	2%	4%	0%
m_2	98%	0%	0%	0%	2%
m_3	0%	6%	50%	44%	0%
Ø	0%	2%	48%	52%	

Note: In each table, each cell not in the last row or column indicates the percentage of markets in which a pair has formed between the row player and column player. The last row reports the percentage of markets in which each respective column player is unmatched, and the last column reports the percentage for each row player.

	EA6	EM6	NA6	NM6	EA7	EM7	NA7	NM7
Panel B. Tests of hypotheses on aggregate outcomes: wave 2								
1a: # matched pairs=3	2.96	2.98	2.88	2.72	2.98	3.00	3.00	2.98
	(1.00)	(1.00)	(3.67)	(3.77)	(1.00)	(·)	(·)	(1.00)
1b: full matching=1	0.98	0.98	0.88	0.74	0.98	1.00	1.00	0.98
	(1.00)	(1.00)	(3.67)	(3.88)	(1.00)	(·)	(·)	(1.00)
2a: # efficiently matched pairs=3	2.92	2.94	1.86	1.80	2.44	2.54	2.42	2.84
	(1.50)	(1.41)	(5.40)	(6.80)	(4.73)	(5.92)	(5.30)	(2.45)
2b: efficient matching=1	0.96	0.96	0.50	0.44	0.68	0.71	0.66	0.92
	(1.50)	(1.50)	(5.51)	(7.80)	(4.71)	(7.66)	(5.67)	(2.45)
2c: % surplus achieved=1	0.99	0.99	0.94	0.91	0.98	0.96	0.97	0.99
	(1.12)	(1.17)	(5.93)	(4.90)	(3.50)	(5.59)	(3.58)	(1.46)
3a: stable outcome=1	0.86	0.74	0.16	0.02	0.02	0.00	0.04	0.04
	(2.09)	(3.88)	(11.70)	(49.00)	(49.00)	(·)	(24.00)	(36.00)
clusters	10	10	10	10	10	10	10	10

Notes: t statistics in parentheses; standard errors clustered at group level

The results of wave 2 are summarized in Table 3. Overall, they confirm the main findings of wave 1, although the matching rate and efficiency rate are higher in wave 2. This is likely due to the change in the ending rule, which allows more time for subjects to react and form new matches after being released by the end of the three minutes. Despite this, the results of wave 2 show that the efficiency rate is still significantly lower than what is predicted by the cooperative theory. In addition, the results for stable outcomes are similar to those in wave 1, with a significant discrepancy between theory and experiment in the proportion of stable outcomes achieved. These findings suggest that subjects are behaving in a way that differs systematically from what the cooperative theory predicts, regardless of the ending rule.

As shown in rows 1a and 1b, the number of matched pairs and the matching rate in most markets were not significantly different from 3 and 100 percent, respectively. However, in NA6 and NM6, the number of matched pairs and the matching rate were significantly lower than the predictions of the cooperative theory. In comparison, the number of matched pairs and the matching rate in NA6 and NM6 improved from wave 1 to wave 2 (from 2.58 pairs and 61 percent to 2.88 pairs and 88 percent in NA6, and from 2.40 pairs and 45 percent to 2.72 pairs and 74 percent in NM6). This improvement may be due to the change in the ending rule, which allowed more time for subjects to react and form new matches. Row 2c shows that the percentage of efficient surplus achieved ranged from 96 percent in EM7 to 99 percent in EA6 and EM6, and from 91 percent in NM6 to 99 percent in NM7. The percentage of efficient matching was not significantly different from 100 percent in EA6 and EM6. However, inefficient matching was still prevalent in other markets, even when full matching was achieved. Overall, by imposing an indefinite ending rule and higher stakes per market, both the number of matched pairs and the percentage of efficient surplus achieved improved compared with wave 1. However, inefficient matching was not eliminated in ESNIC markets.

Row 3a reports summary statistics on stable outcomes. Balanced ESIC markets (EA6 and EM6) have high frequencies of stable outcomes, but other markets do not, and this pattern remains when we restrict our attention to full or efficient matching (Table B1b in online Appendix B). When we consider a relaxation of stable outcomes to stable10 outcomes, most blocking pairs cannot improve their payoffs by more than ten units, but there remains a significant portion of blocking pairs who could have jointly improved their payoffs by more than ten units. In imbalanced markets, there are some occurrences (0–4 percent) of stable outcomes, meaning that some matched players get zero payoffs; in comparison, there was zero instance that matched players get zero in wave 1. However, matched players getting zero payoff, the unique core prediction, remains a rare occasion. The experimental finding that the two duplicate players on the long side of the market do not have their payoffs driven to zero remains.

Determinants of Aggregate Outcomes.—We vary the surplus configurations in the dimensions of whether stable matching is assortative and whether pairwise equal splits are in the core, because we conjecture that in reality, the two dimensions may influence people's actual decisions in matching. Several papers report how strategic complexity affects plays in games. Bednar et al. (2012) demonstrate that the prevalent strategies in games that are less cognitively demanding are more likely to be used in games that are more cognitively demanding. Luhan, Poulsen, and Roos (2017) and He and Wu (2020) show that subjects may not use a certain efficient strategy due to its complexity, but instead settle on a simpler but inefficient strategy. Under nonassortative efficient matching, the stable matching pattern is less obvious. Hence, nonassortative matching—even when pairwise equal splits are in the core—may be perceived by subjects as more complex and more cognitively demanding.

Consequently, subjects may settle on inefficient matching patterns, such as the ones on the diagonals or accept payoffs that are not supported in the core.

Equal splits have been widely observed in bilateral bargaining, especially when they are also efficient. Two arguments are commonly used to support the prevalence of equal splits in the data: the focal point theory of Schelling (1960) and distributional social preferences (Fehr and Schmidt 1999; Bolton and Ockenfels 2000). When equal splits are not efficient, there is mixed evidence on the trade-offs between equality and efficiency; see Roth and Malouf (1979); Hoffman and Spitzer (1982); Roth and Murnighan (1982); Roth, Murnighan, and Schoumaker (1989); Ochs and Roth (1989), Herreiner and Puppe (2010); Roth (1995); Camerer (2003); Anbarci and Feltovich (2013, 2018); Isoni et al. (2014); and Galeotti, Montero, and Poulsen (2018), among many others, on reporting and understanding equal splits in bargaining experiments. In our experiment, efficiency is aligned with stable matching. Hence, when pairwise equal splits are stable, they are also efficient. However, when they are not in the core, subjects will face trade-offs between equality and efficiency, which may negatively affect the rate of matching, the rate of stable matching, and overall efficiency.

HYPOTHESIS 4: *For balanced markets*, (*i*) *the number of matched pairs*, (*ii*) *the number of efficiently matched pairs*, *and* (*iii*) *the percentage of efficient surplus achieved are the same* (*i*) *in assortative markets as in nonassortative markets and* (*ii*) *in ESIC markets as in ESNIC markets.*

Table 2, panel B (wave 1) and Table 3, panel B (wave 2) provide the following comparisons of balanced markets that contradict the hypothesis. First, assortative markets (EA6 and NA6) have a higher number of matched pairs, a higher number of efficiently matched pairs, and a higher aggregate surplus than the nonassortative markets (EM6 and NM6). Second, ESIC markets (EA6 and EM6) have a higher number of matched pairs, a higher number of efficiently matched pairs, and a higher surplus than ESNIC markets (NA6 and NM6). We confirm the statistical significance of these comparisons for balanced markets by running the OLS regression:

$$(1)\quad y_i = \beta_1 \cdot \mathrm{ESIC}_i + \beta_2 \cdot \mathrm{assortative}_i + \beta_3 \cdot \mathrm{ESIC}_i \cdot \mathrm{assortative}_i + \beta_4 \cdot \mathrm{round}_i + \beta_5 \cdot \mathrm{order}_i + c + \varepsilon_g,$$

where i indicates the index of the game (out of 728 balanced markets), y_i is the dependent variable ((log) number of matched pairs in game i, (log) number of efficiently matched pairs in game i, or (log) surplus in game i); $\mathrm{assortative}_i$ is an indicator of whether game i is assortative, ESIC_i is an indicator of whether game i has pairwise equal splits in the core, round_i is the round (out of 7) the same market has been played, and order_i is the order (out of 4) the game is played in. The standard errors are clustered at the group level (recall 26 and 10 groups of subjects played balanced markets and 20 and 10 groups of subjects played imbalanced markets in waves 1 and 2, respectively). We also run the probit model for whether the market achieves full matching, efficient matching, or stable outcome.

Table 4—Determinants of Aggregate Outcomes in Balanced Markets

	log (# matched pairs+1) (1)	log (# efficiently matched pairs+1) (2)	log surplus (3)	Whether full matching (4)	Whether efficient matching (5)	Whether stable outcome (6)
Panel A. Determinants of outcomes in balanced markets: wave 1						
ESIC	0.115	0.426	0.0948	0.328	0.418	0.410
	(7.13)	(10.35)	(4.48)	(6.92)	(9.41)	(11.85)
assortative	0.0556	0.153	0.0366	0.142	0.158	0.0314
	(4.04)	(2.92)	(2.27)	(3.82)	(2.95)	(0.79)
ESIC*assortative	−0.0271	−0.115	0.00265	−0.0119	−0.0540	0.111
	(−1.36)	(−2.04)	(0.12)	(−0.16)	(−0.70)	(1.89)
round	0.00490	0.0206	0.00847	0.0158	0.0283	0.0239
	(2.64)	(3.50)	(3.75)	(2.53)	(4.31)	(3.99)
order	0.0139	0.0294	0.0217	0.0463	0.0514	0.0401
	(3.39)	(2.53)	(3.66)	(3.48)	(3.01)	(3.17)
constant	1.156	0.666	5.023			
	(68.30)	(12.08)	(207.72)			
Observations	728	728	728	728	728	728
clusters	26	26	26	26	26	26
Panel B. Determinants of outcomes in balanced markets: wave 2						
ESIC	0.0803	0.451	0.104	0.234	0.465	0.565
	(3.40)	(6.46)	(3.66)	(3.81)	(8.31)	(7.95)
assortative	0.0484	0.0173	0.0421	0.0788	0.0364	0.223
	(2.70)	(0.19)	(1.64)	(2.19)	(0.57)	(2.79)
ESIC*assortative	−0.0629	−0.0455	−0.0549	−0.0935	−0.0429	−0.131
	(−2.61)	(−0.44)	(−1.68)	(−1.17)	(−0.43)	(−1.16)
round	0.00935	0.0388	0.00743	0.0330	0.0487	0.0408
	(1.60)	(2.94)	(1.04)	(2.18)	(3.40)	(3.15)
order	0.0159	0.0503	0.0199	0.0451	0.0450	0.0150
	(2.28)	(2.02)	(2.97)	(2.51)	(1.70)	(0.53)
constant	1.236	0.683	5.118			
	(37.69)	(7.31)	(208.98)			
observations	200	200	200	200	200	200
clusters	10	10	10	10	10	10

Notes: t statistics in parentheses; standard errors clustered at group level reported coefficients in columns (4)–(6) are marginal effects from probit.

Table 4 reports the regression results. In wave 1 (wave 2), compared with other markets, ESIC markets have 11.5 percent (8.03 percent) more matched pairs, 42.6 percent (45.1 percent) more efficiently matched pairs, and 9.48 percent (10.4 percent) more surplus. In addition, ESIC markets are 32.8 percentage points (pp) (23.4 pp) more likely for full matching, 41.8 pp (46.5 pp) more likely for efficient matching, and 41.0 pp (56.5 pp) more likely for a stable outcome in wave 1 (wave 2). The effects of ESIC are comparable across the two waves. Assortativity has a modest effect on matching and efficiency. Compared with nonassortative markets, assortative markets have 5.56 percent (4.84 percent) more matched pairs, 15.3 percent (1.73 percent) more efficiently matched pairs, 3.66 percent (4.21 percent) more surplus, 14.2 pp (7.88 pp) more full matching, 15.8 pp (3.64 pp) more efficient matching, and 3.14 pp (22.3 pp) more stable outcomes in wave 1 (wave 2). Overall, the effects of assortativity are weaker in wave 2, partially due to the smaller sample size and partially due to an increase in overall efficiency.

Learning mildly improves matching outcomes. Each additional round of play of the same game is associated with 0.49 percent (0.94 percent) more matched pairs, 2.06 percent (3.88 percent) more efficiently matched pairs, and 0.847 percent (0.743 percent) more surplus, and each seven (five) rounds of play of other games ahead of the current game are associated with 1.39 percent (1.59 percent) more matched pairs and 2.17 percent (1.99 percent) more surplus in wave 1 (wave 2). These results are statistically significant at at least the 95 percent level in wave 1, but are partially not significant in wave 2. In online Appendix B, we provide robustness checks with alternative specifications of the regressions regarding dependent variables (no log), rounds of plays, treatment effects, and heterogeneous order effects. The results are consistent with those under our current specifications. We also test to see whether having played any particular market would influence the subsequent outcomes of other markets. We find that no market systematically influences the subsequent outcomes of other markets. In addition, we limit the analysis to only the first rounds of the markets, and the results for the first rounds are consistent with the full results.

Overall, for balanced markets, having pairwise equal splits in the core is a crucial determinant of efficient matches and surpluses, and assortativity plays a less important role. To a much lesser extent but at a statistically significant level, experience with the negotiation process slightly increases the matching rate and efficiency, but the increase is not tied to a particular market type (details in the online Appendix).

Furthermore, we consider the determinants of outcomes when both balanced and imbalanced markets are included. Table 5 presents the results for the following regression model:

$$
\begin{aligned}
(2) \qquad y_i = {} & \beta_1 \mathrm{ESIC}_i + \beta_2 \mathrm{assortative}_i + \beta_3 \mathrm{balanced}_i + \beta_4 \mathrm{ESIC}_i \mathrm{assortative}_i \\
& + \beta_5 \mathrm{assortative}_i \mathrm{balanced}_i + \beta_6 \mathrm{round}_i + \beta_7 \mathrm{round}_i \mathrm{balanced}_i \\
& + \beta_8 \mathrm{order}_i + \beta_9 \mathrm{order}_i \mathrm{balanced}_i + c + \varepsilon_g,
\end{aligned}
$$

where $\mathrm{balanced}_i$ indicates whether the market in game i is balanced.

ESIC increases the number of matched pairs by 11.5 percent (8.03 percent), the number of efficiently matched pairs by 42.6 percent (45.1 percent), and the surplus by 9.48 percent (10.4 percent) in wave 1 (wave 2), and it also increases instances of full matching, efficient matching, and stable outcomes. Assortativity has mixed results. Controlling for other changes, assortativity changes the number of matches by 2.94 percent (0.003 percent), the number of efficiently matched pairs by 6.45 percent (−9.17 percent), and the surplus by 4.32 percent (−0.34 percent) in wave 1 (wave 2). The changes by assortativity are largely insignificant in wave 2. Having one additional player increases the number of matches by 11.0 percent (15.0 percent), the number of efficient matches by 27.4 percent (51.2 percent), and the surplus by 8.31 percent (15.0 percent) in wave 1 (wave 2). Both waves show the significant effects of adding the additional player, and wave 2 is even more conspicuous. In wave 1, playing an

Table 5—Determinants of Aggregate Outcomes in Balanced and Imbalanced Markets

	log (# matched pairs+1) (1)	log (# efficiently matched pairs+1) (2)	log surplus (3)	Whether full matching (4)	Whether efficient matching (5)	Whether stable outcome (6)
Panel A. Determinants of outcomes in all markets: wave 1						
ESIC	0.115	0.426	0.0948	0.307	0.453	0.410
	(7.19)	(10.44)	(4.52)	(6.48)	(8.46)	(11.85)
assortative	0.0294	0.0645	0.0432	0.117	0.0487	0.0314
	(2.89)	(2.16)	(2.60)	(2.93)	(1.12)	(0.79)
balanced	−0.110	−0.274	−0.0831	−0.267	−0.382	0
	(−4.07)	(−3.36)	(−2.16)	(−3.44)	(−3.75)	(·)
ESIC*assortative	−0.0271	−0.115	0.00265	−0.0111	−0.0585	0.111
	(−1.37)	(−2.06)	(0.12)	(−0.16)	(-0.70)	(1.89)
assortative*balanced	0.0262	0.0888	−0.00662	0.0156	0.122	0
	(1.54)	(1.48)	(−0.29)	(0.28)	(1.65)	(·)
round	0.00974	0.0296	0.0130	0.0352	0.0381	0.0239
	(4.70)	(5.05)	(4.72)	(5.00)	(4.31)	(3.99)
round*balanced	−0.00483	−0.00892	−0.00455	−0.0204	−0.00739	0
	(−1.74)	(−1.08)	(−1.28)	(−2.24)	(−0.63)	(·)
order	0.00399	0.0217	0.00694	0.0130	0.0110	0.0401
	(0.84)	(1.70)	(1.02)	(0.74)	(0.63)	(3.17)
order*balanced	0.00993	0.00772	0.0148	0.0304	0.0447	0
	(1.58)	(0.45)	(1.65)	(1.43)	(1.74)	(·)
constant	1.265	0.941	5.106			
	(59.79)	(15.53)	(170.27)			
observations	1,288	1,288	1,288	1,288	1,288	728
clusters	46	46	46	46	46	26
	log (# matched pairs)	log (# efficiently matched pairs+1)	log surplus	Whether full matching	Whether efficient matching	Whether stable outcome
Panel B. Determinants of outcomes in all markets: wave 2						
ESIC	0.0803	0.451	0.104	0.140	0.556	0.361
	(3.50)	(6.64)	(3.76)	(3.81)	(6.60)	(6.64)
assortative	0.0000332	−0.0917	−0.00339	0.00303	−0.124	0.0342
	(0.01)	(−2.68)	(−0.60)	(0.08)	(−3.19)	(0.58)
balanced	−0.150	−0.512	−0.150	−0.284	−0.546	−0.105
	(−4.64)	(−4.55)	(−5.35)	(−3.83)	(−4.15)	(−1.06)
ESIC*assortative	−0.0629	−0.0455	−0.0549	−0.0558	−0.0513	−0.0835
	(−2.69)	(−0.45)	(−1.72)	(−1.19)	(−0.44)	(−1.18)
assortative*balanced	0.0484	0.109	0.0455	0.0440	0.167	0.108
	(2.70)	(1.13)	(1.78)	(1.01)	(1.99)	(1.45)
round	−0.000719	0.0103	0.000223	−0.00789	0.00625	−0.0271
	(−0.44)	(0.98)	(0.07)	(−0.51)	(0.46)	(−2.53)
round*balanced	0.0101	0.0286	0.00721	0.0276	0.0521	0.0531
	(1.71)	(1.73)	(0.95)	(1.54)	(2.35)	(3.91)
order	0.0000189	0.0225	0.00182	−0.000213	0.0131	0.0261
	(0.03)	(1.46)	(0.84)	(−0.03)	(0.60)	(1.13)
order*balanced	0.0159	0.0279	0.0181	0.0271	0.0408	−0.0166
	(2.33)	(0.97)	(2.63)	(2.18)	(1.11)	(−0.58)
constant	1.385	1.195	5.268			
	(269.34)	(17.97)	(356.45)			
observations	399	399	399	399	399	399
clusters	20	20	20	20	20	20

Notes: t statistics in parentheses; standard errors clustered at group level reported coefficients in columns 4–6 are marginal effects from probit additional round of any game increases the matching by 0.974 percent, efficient matching by 2.96 percent, and the surplus by 1.30 percent, but the round and order effects disappear in wave 2.

In summary, having pairwise equal splits in the core continues to play a prominent role in determining matching and efficiency, and assortativity plays a lesser role, both statistically and quantitatively. Adding an additional player helps increase matching and efficiency. Robustness checks with alternative dependent variables and alternative specifications in online Appendix B reach similar conclusions.

B. *Individual Payoffs*

We consider the individual payoffs when efficient matching is achieved and compare them with existing solutions that refine the core (Online Appendix Figure B1 illustrates the core payoffs). In imbalanced markets, the core predicts a zero payoff for a matched player who has a duplicate competitor on the long side of the market. Formal Wilcoxon signed-rank test and t-tests demonstrate that these players' payoffs in the experiment are all statistically significantly above zero (Table B2 and Table B3 in online Appendix B, respectively). There are only a few instances in wave 2 in which a matched player gets a zero payoff. This inconsistency between the core and the experiment warrants further attention, which we address in our noncooperative model.

Tables B4a and B4b in online Appendix B present t-tests between cooperative solutions and the experimental payoffs of balanced markets in waves 1 and 2, respectively. When the t-tests do not detect statistically significant differences, the solution is consistent with the experimental finding. We consider (i) the Shapley value, which assigns each player a payoff relative to how "important" that player is to the overall surplus (Shapley 1953); (ii) the nucleolus, which is the lexicographical center of core payoffs (Schmeidler 1969); (iii) the fair division point, which is the midpoint between row- and column-optimal payoffs (Thompson 1980); and (iv) the median stable matching, which gives each player their median payoff (Schwarz and Yenmez 2011). Among these solutions, the nucleolus and median stable matching do not match the payoffs when the matching is efficient (except for EA6). The fair division point performs well in balanced ESIC markets, but not in NM6 markets. Limit equilibrium values of our noncooperative model, which we present in the next section, match well with (i.e., fall within 2 units of) our experimental values across all markets.

IV. Potential Explanations

A. *Noncooperative Theory*

Existing cooperative solutions—either set-valued ones like the core or singleton-valued ones like the nucleolus—depart from the experimental results in systematic ways. To rationalize the individual payoffs in the experiment, consider the following continuous-time model that captures the essence of our experimental setup. At time zero, no one is matched. At each instant $t \geq 0$, any agent can propose to anyone on the other side of the market. A person who receives a proposal must accept or reject the proposal within time length Δ. Neither a proposer nor a receiver of a proposal can make another proposal within time length Δ. At each instant, when several offers are made simultaneously, proposals from one side of the market are randomly selected to be sent, and whenever tie-breaking is needed next, proposals from the other side of the market are sent.[13] When a proposal is accepted the match becomes temporary, and the temporary match and the temporarily agreed upon division of surplus are publicly announced. People who are temporarily matched can still propose to anyone on the other side of the market other than their matched partner. The game ends when there is no new proposal in the last $\Delta \cdot (1 + \varepsilon)$ units of time, where $\varepsilon \in (0,1)$, and all matches become final. Suppose each individual has a discount rate of r. Define $\delta \equiv e^{-r\Delta}$. Taking $\Delta \to 0$ is equivalent to taking $\delta \to 1$.[14]

We consider the Markov perfect equilibria of the game. At each instant, the state of the game is summarized by the temporary matching μ and the temporary payoffs $\{U_m\}_{m\in M}$ and $\{V_w\}_{w\in W}$. Because of the rule whereby agents cannot make another offer before Δ units of time, in equilibrium, effectively, actions occur only at times that are integer multiples of Δ. Given the specific tie-breaking rule, we can alternatively think of a discrete-time model in which agents have discount factors δ and, in the initial period agents on one side of the market are randomly chosen to propose. In subsequent periods the two sides alternate in making proposals, and the game ends when there is no proposal in a period.

Balanced Markets.—Suppose there is a unique efficient matching μ^* in a balanced matching market, as in the four balanced markets in our experiment. Consider the following (Markov perfect) equilibrium in which players propose to their partners in the efficient matching. At time zero, each man $m \in M$ proposes to woman $\mu^*(m) \in W$ with the surplus division U_m^p to m and $s_{m\mu^*(m)} - U_m^p$ to $\mu^*(m)$, and each woman $w \in W$ proposes to man $\mu^*(w) \in M$ with the surplus division $s_{\mu^*(w)w} - V_w^p$ to $\mu^*(w)$ and V_w^p to w. Each man $m \in M$ accepts the highest acceptable offer, in which an offer above $\delta \cdot U_m^r$ is weakly acceptable and U_m^r is the optimal value when m rejects the current offer. Each woman $w \in W$ accepts the highest offer, where an offer above $\delta \cdot V_w^r$ is weakly acceptable and V_w^r is the optimal value when w rejects the current offer. At each instant after time zero, each person makes an offer that maximizes their payoff given the current temporary payoffs, and each person accepts the highest acceptable offer if it is above their current temporary payoff. On the equilibrium path, each man $m \in M$ proposes to woman $\mu^*(m) \in W$ and each woman $w \in W$ proposes to man $\mu^*(w) \in M$ with the division specified above, and each person accepts the offer at time zero and does not make another

[13] We assume this tie-breaking rule for analytic convenience. Alternative tie-breaking rules, such as having each pair of conflicting proposals being independently determined at each instant, will not change the limit payoffs that match the experimental results, but will introduce complications in the expression of equilibrium payoffs due to combinatorial proposer-receiver possibilities.

[14] The addition of frictions in the form of discount factor (and taking the frictionless limit) has been used as a tool to refine the prediction of a bargaining model since Rubinstein (1982).

offer. The proposal each man $m \in M$ makes to woman $\mu^*(m) \in W$ at time zero yields him a payoff of

$$U_m^p = s_{m\mu^*(m)} - \max\left\{\delta \cdot V_{\mu^*(m)}^r, \max_{m' \in M \backslash m}\left\{s_{m'\mu^*(m)} - U_{m'}^p\right\}\right\}, \tag{3}$$

where

$$V_{\mu^*(m)}^r = s_{m\mu^*(m)} - \max\left\{\delta \cdot U_m^p, \max_{w' \in W \backslash \mu^*(m)}\left\{s_{mw'} - \left[s_{\mu^*(w')w'} - U_{\mu^*(w')}^p\right]\right\}\right\}. \tag{4}$$

Note that $U_{m'}^p$ is the payoff of m' when $\mu^*(m')$ accepts, and $s_{\mu(w')w'} - U_{\mu(w')}^p$ is the payoff of w' when w' accepts. The offer man $m \in M$ proposes to woman $\mu^*(m) \in W$ is $s_{m\mu^*(m)} - U_m^p$, which is the maximum of (i) $\delta \cdot V_{\mu^*(m)}^r$, the continuation value that woman $\mu^*(m) \in W$ can get if she rejects, and (ii) $\max_{m' \in M \backslash \{m\}}\left\{s_{m'\mu^*(m)} - U_{m'}^p\right\}$, the highest possible deviation payoff that another man $m' \in M \backslash \{m\}$ can offer to $\mu^*(m)$. The expected payoff that woman $\mu^*(m) \in W$ gets if she rejects, $V_{\mu^*(m)}^r$, results from her proposing to man $m \in M$, while ensuring that no other woman $w' \in W \backslash \{w\}$ is able to offer $s_{mw'} - \left[s_{\mu^*(w')w'} - U_{\mu^*(w')}^p\right]$ to $m \in M$ to poach him. Analogously, the proposal each woman $w \in W$ makes to man $\mu^*(w) \in M$ at time zero is

$$V_w^p = s_{\mu^*(w)w} - \max\left\{\delta \cdot U_{\mu^*(w)}^r, \max_{w' \in W \backslash w}\left\{s_{\mu^*(w)w} - V_{w'}^p\right\}\right\}, \tag{5}$$

where

$$U_{\mu^*(w)}^r = s_{\mu^*(w)w} - \max\left\{\delta \cdot V_w^p, \max_{m' \in M \backslash \mu^*(w)}\left\{s_{m'w} - \left[s_{m'\mu^*(m')} - V_{\mu^*(m')}^p\right]\right\}\right\}. \tag{6}$$

Note that when $\delta = 1$, all core payoffs satisfy the system of $n_M + n_W$ equations for $\left\{U_m^p\right\}_{m \in M}$ and $\left\{V_w^p\right\}_{w \in W}$. When $\delta < 1$, we can show that there is a unique set of payoffs $\left\{U_m^p\right\}_{m \in M}$ and $\left\{V_w^p\right\}_{w \in W}$ that satisfy the system of equations. The proofs are provided in online Appendix C.

THEOREM 1: *For any $\delta \in (0,1)$, there exists a unique solution to the system of equations (3)–(6). Moreover, if we replace μ^* with any $\mu \neq \mu^*$ in the system of equations (3)–(6), there is no solution.*

Theorem 1 establishes the existence of a unique solution to the system of equations with efficient matching, which is supported as an MPE, and that inefficient matching cannot be supported in any MPE. This result contrasts with Proposition 2, which shows that the set of stable payoffs is not a singleton in the canonical cooperative model. Furthermore, Proposition 3 implies that we should expect the outcome of pairwise equal splits as the unique equilibrium outcome in the limit if and only if it is in the core.

PROPOSITION 3: *Suppose* $s_{mw} > 0$ *for any* $m \in M$ *and* $w \in W$. *There exists a* $\underline{\delta} \in (0,1)$, *such that for any* $\delta \in (\underline{\delta}, 1)$, *when pairwise equal splits are in the core, the equilibrium values are*

$$U_m^p = \frac{s_{m\mu^*(m)}}{1+\delta} \quad \text{for any } m \in M \text{ and } V_w^r = \frac{s_{\mu^*(w)w}}{1+\delta} \text{ for any } w \in W.$$

$$V_w^p = \frac{s_{\mu^*(w)w}}{1+\delta} \quad \text{for any } w \in W \text{ and } U_m^r = \frac{s_{m\mu^*(m)}}{1+\delta} \text{ for any } m \in M.$$

When pairwise equal splits are not in the core, there exists a $\underline{\delta} \in [0,1)$, *such that for any* $\delta \in [\underline{\delta}, 1)$, *the equilibrium values above are not satisfied.*

The expected equilibrium payoffs are $U_m \equiv U_m^p/2 + \left[s_{m\mu^*(m)} - V_{\mu^*(m)}^p\right]/2$ for each $m \in M$ and $V_w \equiv V_w^p/2 + \left[s_{\mu^*(w)w} - U_{\mu^*(w)}^p\right]/2$ for each $w \in W$. These values as $\delta \to 1$ coincide with the payoffs in the experiment. Notably, $U_m^p = U_m^r$ and $V_w^p = V_w^r$ as $\delta \to 1$ in games with pairwise equal splits in the core, but $U_m^p \neq U_m^r$ and $V_w^p \neq V_w^r$ in the two games with pairwise equal splits not in the core, even in the limit as $\delta \to 1$. This suggests that on the one hand, in markets with pairwise equal splits in the core, outside options do not play a role in equilibrium and agents effectively engage in Nash/Rubinstein bargaining in pairs; in other words, market forces are minimal. On the other hand, in markets with pairwise equal splits not in the core, outside threats alter bargaining and influence equilibrium payoffs and market forces play a significant role. These distinctions between markets with and without pairwise equal splits in the core are also observed in noncooperative games with permanently accepted offers (Elliott and Nava 2019; Talamàs 2020; Agranov et al. 2023; Agranov and Elliott 2021). By calculating the equilibrium payoffs in the four balanced markets, we formalize the following hypothesis:[15]

HYPOTHESIS 2a: *The average individual payoffs for men in the four balanced markets are* $U_1 = 15$, $U_2 = 30$, *and* $U_3 = 55$ *in EA6;* $U_1 = 50$, $U_2 = 30$, *and* $U_3 = 20$ *in NA6;* $U_1 = 30$, $U_2 = 50$, *and* $U_3 = 20$ *in EM6; and* $U_1 = 30$, $U_2 = 40$, *and* $U_3 = 30$ *in NM6.*

Figure 1, panel A shows the match between the data and the predictions of our model for balanced markets. The theoretically predicted payoffs in efficient matching fall within the 99 percent confidence interval of the data mean. The theory not only matches well with the average payoff, but also with the more detailed realized behavior. The modal outcome matches the theoretical prediction, shown in Figures B2(a) and B2(c) in online Appendix B for wave 1 and wave 2, respectively. The figures present the histograms of payoffs of individuals in the efficient matching, with bandwidth of 1.[16] In addition, our theory matches other experimental results

[15] We only demonstrate men's payoffs, because women's payoffs are pinned down by men's in efficient matching.

[16] The same pattern holds if we consider all matched individuals—not just the matched individuals in the efficient matching—as shown in online Appendix Figure B3(a) and Figure B3(c), for wave 1 and wave 2, respectively, in online Appendix B.

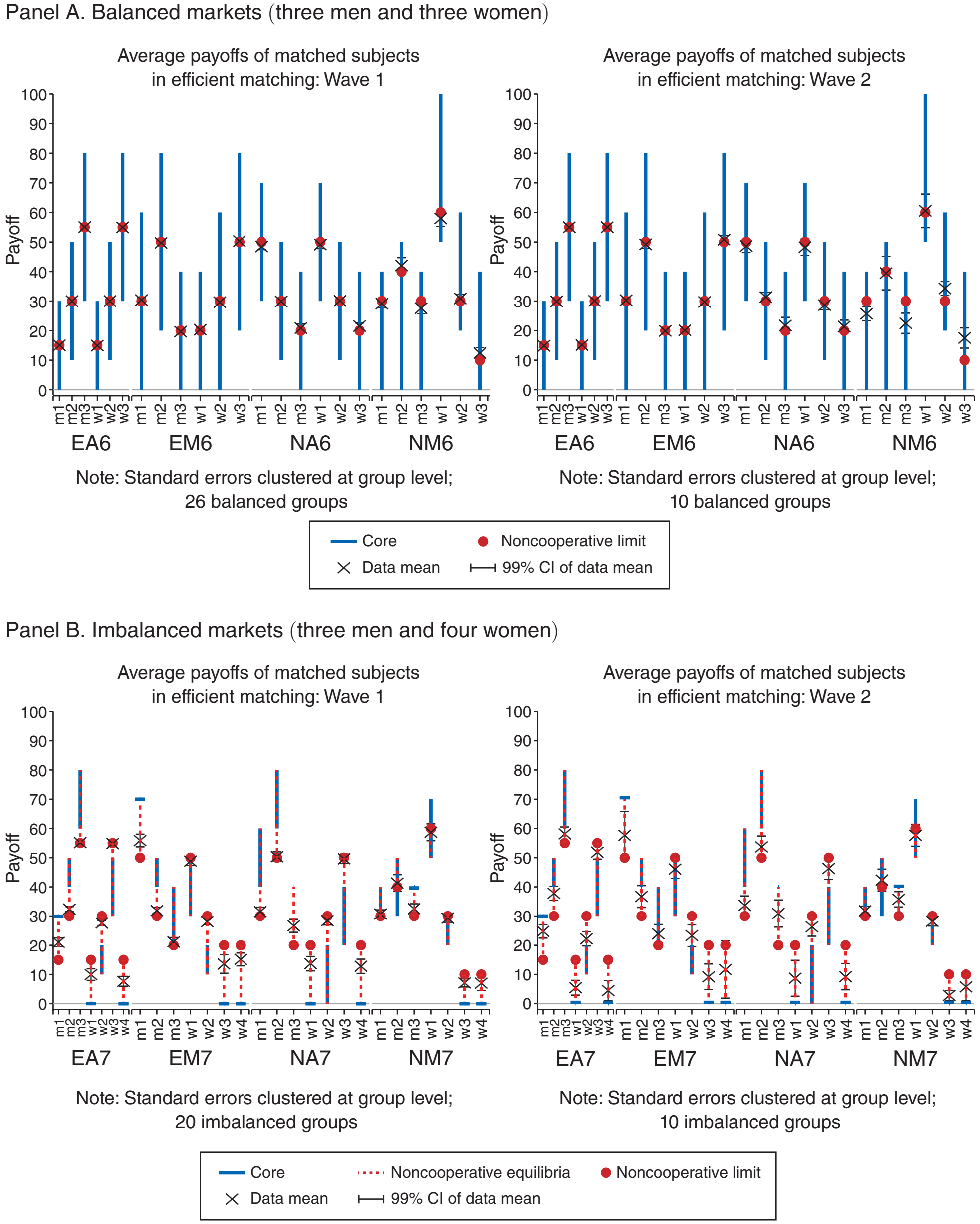

Figure 1. Average Payoffs of Matched Subjects in Efficient Matching

Notes: The figures show the average payoffs of matched individuals in efficient matching. Blue intervals indicate the range of values in the core. Red dots in balanced markets indicate the noncooperative equilibrium payoffs in the frictionless limit. The red dashed lines in imbalanced markets indicate the range of noncooperative equilibria and red dots indicate the payoffs in the noncompetitive equilibrium in the frictionless limit. Crosses indicate data mean and the segments indicate 99 percent confidence intervals of data mean. The figures show that average experimental payoffs in balanced markets are predicted by the limit equilibrium payoffs in our noncooperative model, and average experimental payoffs in imbalanced markets are not in the core but are between the competitive and noncompetitive equilibrium payoffs in our noncooperative model.

in the literature with comparable experimental settings, as summarized in online Appendix Table B5, which reports the surplus matrices in other experiments, their types according to categorization of assortativity, ESIC, and balancedness, as well as average payoffs of all and/or efficient matches, with standard errors included whenever they are reported. By our categorization, all of the surplus matrices in previous experiments are assortative, while some have pairwise equal splits in the core and some do not. In comparison, we vary whether pairwise equal splits are in the core and examine markets with nonassortative surplus matrices.

Imbalanced Markets.—Consider an imbalanced market in which two individuals are identical in terms of the surplus they generate with anyone on the other side of the market; in the four imbalanced markets in our experiment, we have w^*, $w^{**} \in W$ such that $s_{mw^*} = s_{mw^{**}}$ for all $m \in M$. There are two efficient matching outcomes μ^* and μ^{**} such that between w^* and w^{**}, only w^* is matched and only w^{**} is matched, respectively.

There are various (Markov perfect) equilibrium outcomes in this imbalanced market, in the spirit of the folk theorem. To fix ideas, consider the simplest imbalanced matching market of one man m^* and two women w^* and w^{**}, with either pair being able to generate a surplus of $s^* > 0$. In the first type of equilibrium, man m^* proposes to either woman w^* or woman w^{**} a division of the surplus s^* into s^* for himself and 0 for her; woman w^* and woman w^{**} propose to man m^* the same division; man m^* accepts a payoff weakly above s^*; and each woman accepts any division of surplus. The equilibrium outcome is a core outcome in an imbalanced matching market, and is what we call a competitive outcome, since the two women are competing to benefit the man on the short side of the market. However, in this dynamic noncooperative setting, there are other equilibrium outcomes. Consider the following equilibrium strategies. When man m^* is unmatched, woman w^* proposes to man m^* the Rubinstein division of surplus $*$ with $s^*/\left(1 + \delta\right)$ for her and $\delta \cdot s^*/\left(1 + \delta\right)$ for the man; man m^* proposes to woman w^* the Rubinstein division $s^*/\left(1 + \delta\right)$ for himself and $\delta \cdot s^*/\left(1 + \delta\right)$ for woman w^*, and accepts any offer above $\delta \cdot s^*/\left(1 + \delta\right)$ and above his current temporary payoff. When m^* is matched with w^{**}, woman w^* proposes to man m^* the competitive division of surplus s^* with s^* for man m^* and 0 for woman w^*, and man proposes to woman w^* the same competitive offer. Woman w^{**} does not propose or accept any offer. This is an optimal strategy for woman w^{**}, since she knows that any proposal to or any acceptance of a proposal from man m^* would still lead to a zero payoff for her. We call this equilibrium outcome a noncompetitive outcome, since the agents on the long side of the market—the women—are not competing. Finally, using this "grim-trigger" type of strategy, any equilibrium outcome that yields a payoff U between $\delta \cdot s^*/\left(1 + \delta\right)$ and s^* for man m^* is possible if woman w^{**} accepts any offer that yields a payoff weakly above $s^* - U$. This results in a partially competitive outcome in which men benefit from some competition but not maximally.[17]

[17] This indeterminacy resonates with Rubinstein and Wolinsky (1990), who employ a noncooperative setting with permanently accepted offers.

We can generalize these arguments to imbalanced matching markets with more individuals in which there are two identical women w^* and w^{**}. Consider a generalization of the noncompetitive equilibrium described above, in which each man $m \in M$ and each woman $w \in W \backslash \{w^{**}\}$ behave as if they are in the equilibrium in balanced market with μ^* being the equilibrium matching with woman $w^{**} \in W$ remaining unmatched and woman $w^{**} \in W$ not attempting to make or accept a proposal. For any woman $w \in W \backslash \{w^{**}\}$, whenever man $\mu^*(w) \in M$ is temporarily matched with woman w^{**}, woman w would choose to make a proposal that yields a payoff $s_{\mu^*(w)w^{**}}$ for man $\mu^*(w)$. Given this grim-trigger strategy of any woman $w \in W \backslash \{w^{**}\}$, woman w^{**} has no (strict) incentive to propose to or accept a proposal from any man, because she knows that eventually she will receive a payoff of 0. Analogously, we can have matching μ^{**} be sustained in equilibrium in a similar way. In this type of equilibrium, despite the imbalance of the market, the short side does not benefit from it.[18]

The second class of equilibria generalizes the other extreme of competitive equilibrium in which women w^* and w^{**} compete for man $\mu^*(w^*) = \mu^{**}(w^{**}) \equiv m^*$. In this class, both woman w^* and woman w^{**} propose to man m^* a division of surplus $s_{m^*w^*} = s_{m^*w^{**}} \equiv s^*$ with payoff s^* for man m^* and 0 for herself; meanwhile, man m^* proposes to either woman w^* or woman w^{**} the same division of surplus.

These offers yield a payoff of $U_{m^*} = s^*$ for man m^* and 0 for w^* and w^{**}. There are two possibilities for the other pairs of agents. First, they may be unaffected by these competitions between w^* and w^{**}, since they continue to obtain the noncompetitive outcome in equilibrium, and they can maintain those noncompetitive outcomes by invoking grim-trigger strategies. Second, agents on the long side of the market may be influenced by the competition with the unmatched woman w^{**}. To maximally deter the unmatched woman, matched women may actively choose to offer $s_{\mu^*(w)w^{**}}$ to man $\mu^*(w)$ so that he has no incentive to match with woman w^{**}, and woman w^{**} has no way to poach man $\mu^*(w)$. The maximum deterrence is to offer $s_{\mu^*(w)w^{**}}$ to the man, but any payoff between $s_{\mu^*(w)w} - V_w^p$ and $s_{\mu^*(w)w^{**}}$ for man $\mu^*(w)$ can be supported in equilibrium for any woman w, which generates a range of equilibrium outcomes.

In the experiment, the core payoffs—the competitive outcome—are not the most plausible predictions for these imbalanced matching markets. As a consequence, any refinement of the core with the cooperative approach will not yield a satisfying prediction for the imbalanced markets. Rather, we observe a range of payoffs for men and women between the competitive outcome and the noncompetitive outcome, as shown by the histograms of realized individual payoffs. This multiplicity is also observed in other experiments. For example, Leng (2023) meticulously follows the continuous-time setup of Perry and Reny (1994) that supposedly generates only core outcomes; a range of noncore outcomes analogous to our noncompetitive

[18] Note that the folk-theorem-like equilibrium multiplicity in imbalanced markets is not possible in balanced markets in which individuals can make additional nonbinding offers. A threat to a competitor in a balanced market is not credible, because the competitor has a positive "outside option" with another partner. A threat to an agent on the opposing side is also not credible, because offers can be made by both sides; think of bilateral Rubinstein bargaining as a balanced market with one agent on each side: There is a unique Markov perfect equilibrium.

outcomes arises in markets with unequal numbers of participants on the two sides (to be precise, markets with one seller and two buyers).

HYPOTHESIS 2b: *The ranges of payoffs are*

$$U_1 \in [15,30], U_2 \in [30,50], U_3 \in [55,80], V_1 \in [0,20],$$

$$V_2 \in [10,30], V_3 \in [30,55], V_4 \in [0,15] \text{ in EA7;}$$

$$U_1 \in [30,70], U_2 \in [30,50], U_3 \in [20,40], V_1 \in [30,50],$$

$$V_2 \in [10,30], V_3 \in [0,20], V_4 \in [0,20] \text{ in EM7;}$$

$$U_1 \in [30,60], U_2 \in [50,80], U_3 \in [20,40], V_1 \in [0,20],$$

$$V_2 \in [0,20], V_3 \in [20,50], V_4 \in [0,20] \text{ in NA7;}$$

$$U_1 \in [30,40], U_2 \in [40,50], U_3 \in [30,40], V_1 \in [50,70],$$

$$V_2 \in [20,30], V_3 \in [0,10], V_4 \in [0,10] \text{ in NM7.}$$

Adding one player to a balanced market shrinks the core. The payoffs of players on the short side of the market increase, and those of players on the long side decrease; some matched players' payoffs are driven to zero in the cases we consider in our experiment. However, experimentally, players' average payoffs do not change that drastically, as shown in Figure 1b. Only a few participants in wave 2 end up with the competitive core outcome of zero payoffs. The noncompetitive outcome is much more frequent. Online Appendix Table B6 shows the proportion of instances in predicted payoff ranges of matched players in imbalanced markets. As can be seen in the table, most individual payoffs fall in our model's predicted range supporting the hypothesis, but outside the canonical model's predicted range.

Figure B2b and Figure B2d in online Appendix B show that the modal payoffs of matched players continue to be the noncompetitive payoffs in both wave 1 and wave 2; the same pattern holds if we consider all matched individuals—not just the matched individuals in efficient matching—as shown in Figures B3b and B3d in online Appendix B. Furthermore, notably, although they are on the long side of the market, women with the highest bargaining power gain slightly in imbalanced markets (online Appendix Figure B4). This in general supports our prediction of a noncompetitive equilibrium in imbalanced markets.

Overall, there is some competition, which is an equilibrium outcome in our noncooperative model. There is enough competition to reject the noncompetitive outcome as the sole outcome, but competition does not drive the relevant players' payoffs to zero or affect other players' payoffs drastically. Payoffs remain close to the noncompetitive outcome. In general, if the observed payoffs are not predicted by our noncompetitive limit payoffs, then the observed payoffs are between our noncompetitive limit payoffs and the lower (upper) bound of core payoffs for players on the short (long) side of the market.

B. *Fairness Concerns*

The theoretic prediction that matched individuals receive no benefit or pairs divide surpluses extremely unequally occurs rarely in experiments. For example, some individuals on the long side of imbalanced markets are predicted by the core to have zero payoffs even if they are matched, because of competition with other individuals, but our experiment shows that the extremely competitive outcomes do not occur frequently, if at all. One explanation is presented above by the folk-theorem-like logic in the noncooperative setting, where many noncompetitive or partially competitive outcomes can be supported. However, the extreme outcomes can still be supported in equilibrium, and the set of equilibria may depend on the bargaining protocol. Alternatively, inequality aversion proposed by Fehr and Schmidt (1999) and Bolton and Ockenfels (2000), which is experimentally and empirically verified by the rich subsequent literature, may provide another explanation. When examining the behavior of subjects in our experiment, we find evidence that they exhibit inequality-aversion preference when they choose between proposals. The results are presented in online Appendix Table D6 and discussed in online Appendix D.2.

Extreme outcomes often involve unequal allocations of resources between matched partners, so for individuals who are averse to inequality, extreme outcomes may not be easily sustained. Motivated by the possible usefulness of incorporating fairness in matching settings to eliminate implausible extreme outcomes, we investigate how matching and bargaining outcomes change when individuals have additional fairness concerns in the form of inequality aversion. This investigation may lend an explanation to why firms pay wages above workers' marginal product, and may have implications for setting minimum wages.

We revise preferences over payoffs following Fehr and Schmidt (1999). Agents are averse to having a lower material payoff than their partner (*disadvantageous inequality aversion*) as well as a higher material payoff (*advantageous inequality aversion*). Namely, when one gets x and their partner gets $y = s - x$, their utility is

$$U(x,y) = x - \alpha \cdot (x - y)_+ - \beta \cdot (y - x)_+,$$

$$V(x,y) = y - \alpha \cdot (y - x)_+ - \beta \cdot (x - y)_+,$$

where $\alpha \in [0,1]$, $\beta \in [0,1]$, and $z_+ = \max\{0,z\}$. In other words, when i gets x and j gets y, then i's utility is $x - \alpha(x - y)$ if $x \geq y$, and $x - \beta(y - x)$ otherwise. Their material payoffs and utilities are zero from staying unmatched. Nunnari and Pozzi (2022) synthesize that the historical estimates of 85 papers are $\alpha = 0.290$ and $\beta = 0.426$ with 95 percent confidence intervals of $[0.212, 0.366]$ and $[0.240, 0.620]$, respectively.

Let *fair core* denote the core when their utilities over payoffs are in the form above. A couple's division of surplus $x + y = s$ when expressed in terms of utilities is

$$(1 + 2\beta)\left(\max\left\{U(x,y), V(x,y)\right\} - s/2\right)$$
$$= (1 - 2\alpha)\left(s/2 - \min\left\{U(x,y), V(x,y)\right\}\right).$$

Potential deviators who earn utilities U and V in their current match do not have incentives to match to divide s:

$$(1 + 2\beta)\left(\max\left\{U, V\right\} - s/2\right) \geq (1 - 2\alpha)\left(s/2 - \min\left\{U, V\right\}\right).$$

Online Appendix Figure B1 illustrates the core, the fair core, and noncooperative payoffs for each of the balanced and imbalanced markets. Some comments follow.

First, the fair core is far from unique. It continues to provide a broad set of predictions.

Furthermore, the fair core is not a subset of the core (and neither is the core a subset of the fair core), so it is not a refinement of the core. One may think that inequality aversion consideration shrinks the payoff gap between matched agents and consequently shrinks the set of fair core payoffs. The consideration indeed shrinks the payoff gap between matched agents when one agent is getting close to zero payoff, and hence eliminates the extreme divisions in the fair core (e.g., in imbalanced markets). However, the consideration also changes agents' outside options from negotiating with other agents, which determines their bargaining power. Because of fairness concerns, agents' outside options may improve or worsen, which in turn affect their fair core payoffs in a way that differ from their core payoffs.

Note that if the equal-splits outcome is in the core, the outcome is still in the fair core for any combination of α and β. Connecting to the experiment, this theoretical result provides an alternative justification for the robustness of matching with equal splits in the core.

In the two balanced ESNIC markets, the experimental payoffs are illustrated to be outside the fair core. This result suggests that fairness concerns cannot help predict the experimental payoffs.

In imbalanced markets, extreme divisions that involve zero payoffs are eliminated from the fair core: The payoffs below $(\beta/(1 + 2\beta))s$—6.9, 2.9, 9.2, and 9.2, respectively—are eliminated from the predictions, because these payoffs would not give the players a utility higher than zero. This prediction is in contrast to the noncooperative prediction that extreme payoffs can still be supported as part of equilibrium. However, in the fair core, only those payoffs can be supported: Any payoffs above those will be blocked by the unmatched agent who is happy with any positive payoff. Effectively, under any point estimates of β, the fair core predicts a unique value and hence a negligible portion of the experimental payoffs.[19]

[19] If we take a more relaxed stance on the estimates of β by using the 95 percent confidence interval $\beta \in [0.240, 0.620]$, the payoffs are predicted to be in the interval $[4.86, 8.30]$, $[1.62, 2.76]$, $[6.48, 11.07]$, and $[6.48, 11.07]$, respectively. The proportions of experimental payoffs of subjects that fall in the predicted ranges are 0 percent–61 percent in wave 1 and 1 percent–55 percent in wave 2, lower than those of noncooperative predictions.

V. Conclusion

We experimentally investigated an influential class of matching models that has received extensive theoretical and empirical scrutiny. Our contributions are threefold. First, we find that factors that are abstracted away in the basic apparatus play important roles in determining the rate of matching, stability, and efficiency. Specifically, both (i) whether agents can sort on their productivity and (ii) whether agents can split their surpluses by half as a sustainable outcome influence the outcome of the two-sided matching market. Second, we provide a noncooperative theory that makes a unique prediction regarding individual payoffs in balanced markets, which is experimentally supported by our results and results in the literature. Third, we investigate imbalanced markets and find that noncompetitive outcomes may arise both theoretically and experimentally. In addition, we show that inequality aversion plays a role in affecting the subjects' behavior in the experiment. However, incorporating inequality aversion into the cooperative model cannot fully rationalize the experimental results.

Cooperative models offers economists a simple way to study the outcomes of complex strategic interactions, bypassing the complexity of noncooperative approaches. In this paper, we create an experimental setting to evaluate the cooperative models as naturally as possible, yet acknowledging that it inevitably includes the dynamic essence of real-world matching scenarios. The core predictions of cooperative models, when tested against our experimental setting, lack precision in balanced markets and overly emphasize competitive effects in unbalanced markets. Our results suggest the importance of strategic considerations in dynamic interactions. These considerations are relevant for welfare implications in applied research of matching markets, especially those with a dynamic nature.

In online Appendix D, we investigate the determinants of the players' proposing activities. First, we find that proposers are more likely to propose to a receiver when their total surplus stands out among all of the matches the proposer can achieve. Second, they are more likely to propose to a receiver if they appear more attractive to the receiver. Third, they are more likely to propose (equally) to someone who is at their diagonal positions only when the markets are assortative, and they appear to use equal-split as a heuristic for making proposals when they are inexperienced. Fourth, the number of proposals is significantly lower in the ESIC markets than in the ESNIC markets, and this difference is entirely driven by the number of inefficient proposals. This finding aligns with the prediction of the model that the outside options only affect equilibrium outcomes in the ESNIC markets. Finally, when deciding whether to accept or reject a proposal compared to their current matches, subjects care about not only their earnings but also the fairness level of the proposals. The existence of unmatched individuals suggests that there are still frictions present in our experimental design that prevent people from being fully matched. In this online Appendix, we take a detailed look at the behavior of unmatched individuals in the experiment and break down the possible reasons they remain unmatched. We also find that demographic characteristics do not play an important role.

Our experiment serves as an initial step in understanding decentralized matching and bargaining markets by considering three-by-three and three-by-four markets.

Interesting next steps worth pursuing include investigating (i) the outcome when the market is larger (e.g., six-by-six markets or 12-by-12 markets) in order to study the effects of market thickness on stable bargaining outcomes; (ii) the effects of more imbalanced ratios of the two sides (e.g., three-by-six or 6-by-12 markets) and hence more competition on aggregate and individual outcomes of the market; (iii) the effects of different bargaining protocols on outcomes; and (iv) the effects of asymmetric information on outcomes.

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